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Review

Pinto Beans (*Phaseolus vulgaris* L.) as a Functional Food: Implications on Human Health

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Abstract: Most foods are considered functional in terms of providing nutrients and energy to sustain daily life, but dietary systems that are capable of preventing or remediating a stressed or diseased state are classified as functional foods. Dry beans (*Phaseolus vulgaris* L.) contain high levels of chemically diverse components (phenols, resistance starch, vitamins, fructooligosaccharides) that have shown to protect against such conditions as oxidative stress, cardiovascular disease, diabetes, metabolic syndrome, and many types of cancer, thereby positioning this legume as an excellent functional food. Moreover, the United States has a rich dry bean history and is currently a top producer of dry beans in the world with pinto beans accounting for the vast majority. Despite these attributes, dry bean consumption in the US remains relatively low. Therefore, the objective of this manuscript is to review dry beans as an important US agricultural crop and as functional food for the present age with an emphasis on pinto beans.

Keywords: pinto beans; dry beans; functional food; phenolic compounds; legumes; nutraceuticals

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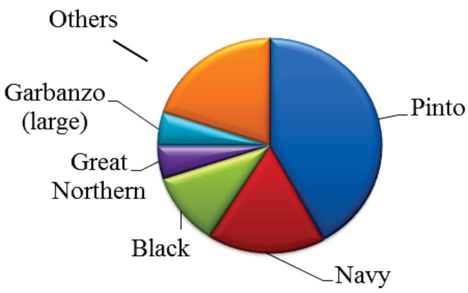
1. Introduction

Dry beans (*Phaseolus vulgaris* L.) or common beans, have been characterized as a nearly perfect food because of their high protein, fiber, prebiotic, vitamin B, and chemically diverse micronutrient composition [1,2]. Dry beans can also be grown in a variety of eco-agricultural regions and distributed in multiple forms, such as whole unprocessed seeds, as part of mixes, canned products, or as a gluten free wheat flour substitute. As a result, dry beans are used throughout the world representing 50% of the grain legumes consumed as a human food source. Alternatively, overall US intake of dry beans is low despite links to reduced disease risks or states prevalent in western cultures, such as oxidative stress, inflammation, cancer, heart disease, and metabolic syndrome [3]. Of the 14 different market classes grown in the US, the pinto bean account for vast majority in terms of production (Figure 1) and consumption [4]. Although all the market classes contain similar major components (protein, fat, carbohydrates, minerals), each have unique minor chemical profiles that can affect their functional food outcomes. Yet, dry beans are understudied with research programs remaining critically underfunded compared to other commodities. Therefore, the objective of this review is to provide information on dry beans as an important crop not only for the US agriculture sector (past and present) but as a potential functional food for western societies with an emphasis on pinto beans.

Figure 1. Market classes of dry beans produced (in total percent) (adapted from USDA data [4]). (Others include small white, light red kidney, dark red kidney, lima, black-eyed, cranberry, and pink.)



2. Agriculture Development of Dry Beans

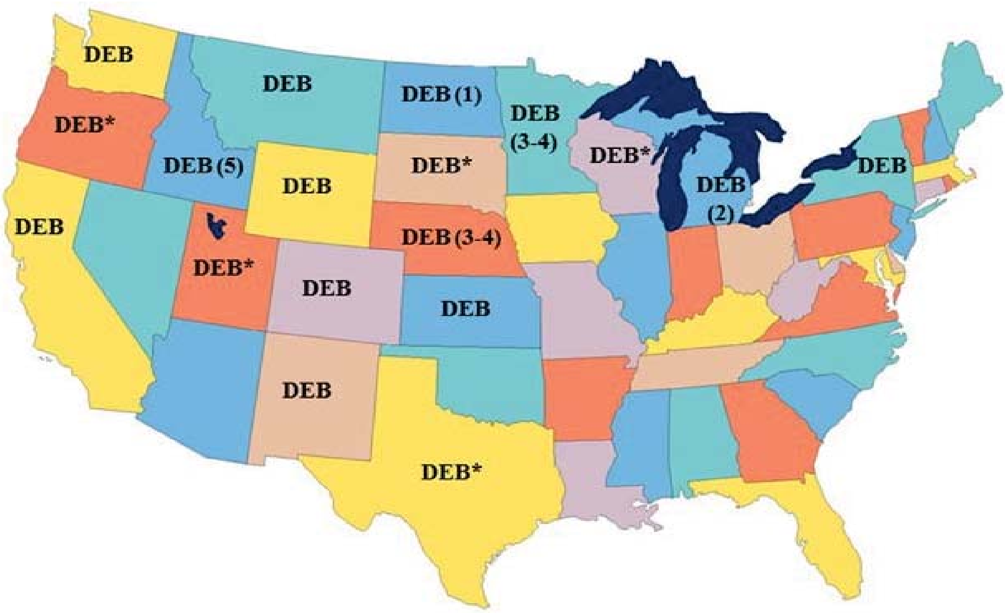
The dry bean is truly a "new world crop" originating 7000 years ago in two different parts of the North and South American continents [5,6]. The clear separation of the two domestication centers, *i.e.*, Mesoamerica (southern Mexico and Guatemala) and regions along the Andes mountain range (principally Peru and Columbia), resulted in the small seeded Mesoamerican beans and the large seeded Andean gene pools. The Mesoamerican beans spread northward during the next several millennia to what is now the US, Canada, and the Caribbean Islands whereas the Andes migrated throughout South America to the eastern coast.

In the US, dry beans can be traced to 1300 AD, specifically in the northeast where they played an important role in the "three sisters" farming practices of the Native American Indians. As the middle sister to corn and squash, dry beans fixed nitrogen in the soil supplying fertilizer to its two sisters. Corn provided a trellis for the beans to grow while squash served as a cover crop preventing moisture, evaporation and weed pressure. The three sisters in combination provided most of the daily nutrients needed for a balanced diet.

It was not until the 15–16th century that dry beans crossed the Atlantic Ocean. Spanish and Portuguese explorers first transported dry beans to Europe and Africa, respectively, where beans then spread rapidly to the rest of the world [2]. Dry beans have since evolved into multiple market classes and are grown/consumed in most parts of the world. Currently, Brazil is the No. 1 producer growing on average 3.2 million metric tons (mmt) followed by India, Myanmar, and China growing ~3.0 mmt, 1.7 mmt, and 1.2 mmt, respectively, on a per annual basis [7]. The US and Mexico fluctuate between the 5th and 6th position producing ~1.0 mmt of dry beans per year [7].

New York was the first US state on record to grow dry beans and was the leading producer from the 1800s until the early 1900s when Michigan assumed this position. Commercial production of dry beans is now scattered across 19 states with North Dakota, Michigan, Nebraska, Minnesota and Idaho being the leaders relative to total yields (Figure 2). These states have remained in the top five positions for the last decade with Nebraska and Minnesota switching in the 3rd and 4th ranking depending on the year. Typically, Nebraska exceeds the other top ranking states in yield per acre. According to the USDA 2010 statistics [8], Nebraska produced on average 910 kg/acre (2010 lbs/acre) of dry beans followed by Idaho (860 kg/acre, 1900 lbs/acre), Michigan (820 kg/acre, 1800 lbs/acre), and North Dakota (657 kg/acre, 1490 lb/acre). Pinto beans account for the largest market class produced in the US and are grown in most of the dry bean growing states (Figure 2) with the navy and black beans following a distance 2nd and 3rd [4,9,10] (Figure 1).

Figure 2. States that produce dry beans [9].



* Represents states that entered production after 1990. States with (number) represents overall ranking in terms of total amount of dry beans produced in 2010.

The dry bean is a staple food in Latin America, Africa, and India [11], but intake in the US and other western societies is substantially low in comparison. US consumption of dry beans is on average ~6.5 lbs (2.95 kg) per person per year with pinto beans again being the top choice. Whole pinto beans are usually purchased as canned pre-cooked or plastic packaged dry beans and are then taken to private homes where they are prepared as ingredients for other foods, such as soups, casseroles, Latin American dishes, or salads. Approximately 75%–80% of bean consumption takes place in the home, while the remaining 20%–25% occurs at restaurants, as fast foods, or in cafeterias [12]. Mexican Americans or other Hispanics are the highest consumers of pinto beans with equal intake occurring by men and women (31–50) regardless of ethnicity [3]. The rising Hispanic population has been credited with the mainstream consumption of all types of cooked beans in the US [12].

3. Composition of Dry Beans

The compositional profile of dry beans in general, and pinto beans specifically, are included in this section to provide possible links to their disease protecting properties, as discussed in Section 4. Although a critical gap in knowledge exists on these mechanisms, dry beans currently hold two positions on the newly developed US MyPlate nutrition guide [13]. Firstly, dry beans are grouped with meat, fish, eggs, nuts as a high source of protein. Dry beans supply approximately 8%–10% of the daily recommended allowance of protein per 100 g serving of cooked beans with methionine being the only absent essential amino acid. Secondly, dry beans are categorized with the vegetable group due in part to their high fiber content. Dry beans are also composed of several types of prebiotics, including resistant starch (RS) and the fructooligosaccharides, stachyose and raffinose [14]. These compounds serve as substrates for bacterial fermentation in the human intestine, thereby influencing the microbial ecology of the gastrointestinal (GI) tract and gut metabolism [15,16]. Additionally, dry beans contain iron and calcium at levels that respectively fulfill ~11 and 2%–6% (100 g serving) of the daily reference intake (DRI) for a 2000 Calorie (kcal) diet. Of the vitamins, the B vitamins are present in particularly high levels. One cup of beans (225 g cooked) supplies ~74% of folic acid (vitamin B9) [17]. This nutrient supports multiple biological functions, including synthesis, repair and methylation of DNA, and acts as a cofactor in many reactions [18]. Folic acid is needed for healthy blood cell production to prevent anemia in children and adults [19]. In addition, one cup of beans provides ~30% of the DRI for vitamin B6 and at least 25% of the DRI for thiamin [17]. Lastly, dry beans (100 g cooked) contain vitamins A and C that account for 3%–8% of the DRI. Table 1 shows the basic compositional profiles of the cited compounds relative to pinto beans.

Considerable less fat-soluble nutrients are present in dry beans as total lipid levels are low (1%–2%). Still, the lipid fraction contains the essential vitamins, E and K. One cup of beans provides ~11% and ~5% DRI of Vitamin E and K, respectively [17]. Vitamin E is a potent antioxidant and anti-inflammatory agent with the isomers α-tocopherol and γ-tocopherol being the most abundant forms in dry beans [20–22]. Vitamin K intake is widely associated with bone health, but has been linked to anti-cancer properties [23–26]. Polyunsaturated fatty acids (PUFAs) represent another important lipid class of compounds present in dry beans, specifically the omega fatty acids (linoleic acid (*n*-6) (LA) and alpha linoleic acid (*n*-3) (ALA)) [27]. Epidemiologic studies have shown overall improvement in the health of individuals with coronary heart disease (CHD) when fed the alpha linolenic acid (*n*-3) (ALA) [28]. After absorption into a cell, LA is elongated and desaturated to arachidonic acid while ALA is elongated and desaturated into eicosapentaenoic acid (EPA) and then into docosahexaenoic acid (DHA). EPA and DHA are omega-3 fatty acids prevalent in fish that have received intense interest due to their cardioprotective and anti-inflammatory properties [29,30]. Leukotrienes, prostaglandins, and thromboxanes, metabolic products derived from AA are generally pro-inflammatory and proaggregatory agonists, while those derived from the ALA are able to inhibit platelet aggregation and inflammation. The latter mechanisms are involved in the prevention of cardiovascular disease (CVD), hypertension, type 2 diabetes, chronic obstructive pulmonary disease, among others [31]. In particular, pinto beans contain ~0.3 grams of ALA per 100 g of raw portion [32]. The fatty acid levels present in pinto beans are shown in Table 1 based on their degree of saturation. (The reader is referred to Winham *et al.* [33] for compositional information relative to other types of dry beans.)

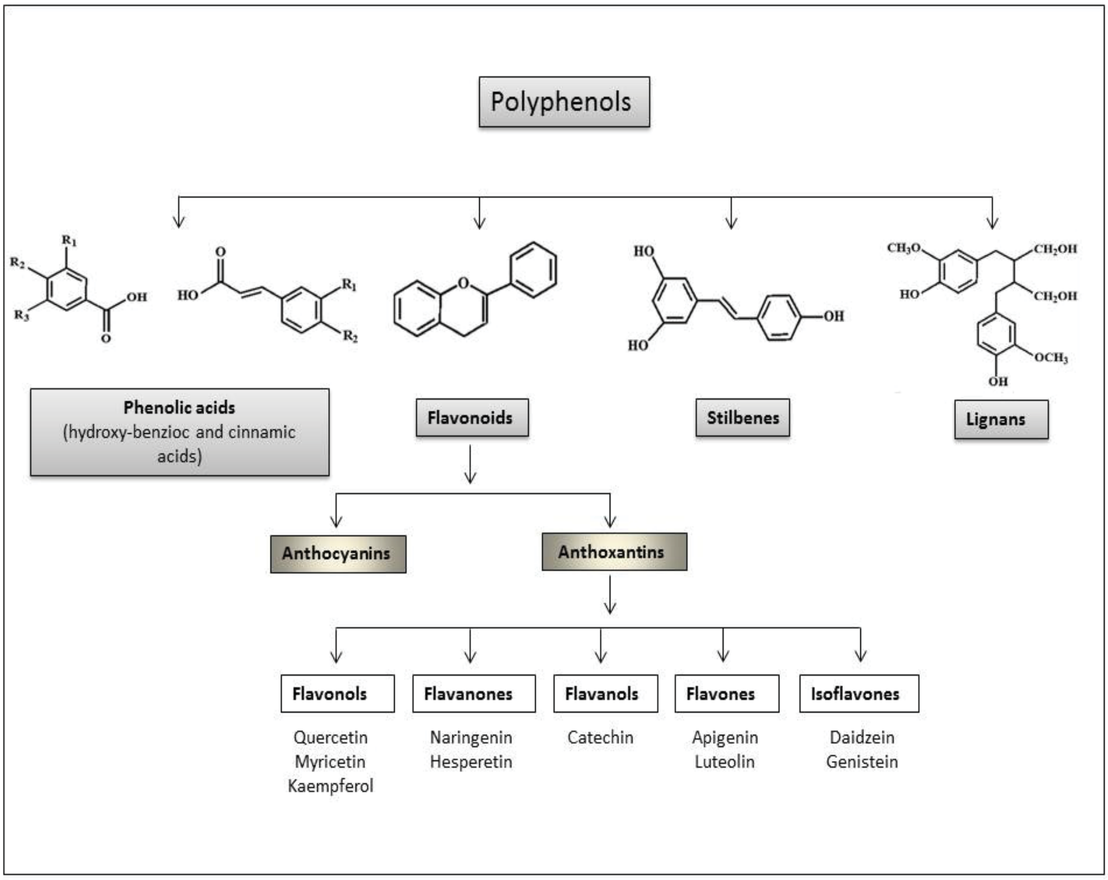
Table 1. Nutritional components of raw and cooked pinto beans (USDA database [34]).

Nutrient	Value per 100 g	
	Raw	Cooked *
Proximates		
Energy	347.00 kcal	143.00 kcal
Protein	21.42 g	9.01 g
Total fat	1.23 g	0.65 g
Carbohydrate	62.55 g	26.22 g
Fiber, total dietary	15.50 g	9.00 g
Sugars, total	2.11 g	0.34 g
Minerals		
Calcium (Ca)	113 mg	46 mg
Iron (Fe)	5 mg	2 mg
Magnesium (Mg)	176 mg	50 mg
Phosphorus (P)	411 mg	147 mg
Potassium (K)	1393 mg	436 mg
Sodium (Na)	12 mg	1 mg
Zinc (Zn)	2 mg	1 mg
Vitamins		
Vitamin C (total ascorbic acid)	6.30 mg	0.80 mg
Thiamin	0.71 mg	0.19 mg
Riboflavin	0.21 mg	0.06 mg
Niacin	1.17 mg	0.32 mg
Vitamin B6	0.47 mg	0.23 mg
Folate, DFE	0.53 mg	0.17 mg
Vitamin E (alpha-tocopherol)	0.21 mg	0.94 mg
Vitamin K (phylloquinone)	5.6 µg	3.5 µg
Lipids		
Fatty acids (total saturated)	0.24 g	0.12 g
Fatty acids (total monounsaturated)	0.23 g	0.13 g
Fatty acids (total polyunsaturated)	0.41 g	0.24 g

* without addition of salt.

In addition to the nutrients described previously, other phytochemicals are present in dry beans but at low levels (parts per million or parts per billion). Nonetheless, these phytochemicals (phenolic compounds, lignins, lectins, and trypsin inhibitors) exert potent protective properties against multiple chronic conditions with the phenols playing a major role [35–40]. Figure 3 illustrates the different classes phenols based on their chemical structures. As over 8000 structurally distinct phenols have been identified [41], numerous quantities and combinations can arise affecting their physiochemical characteristics and thus their bioavailability and biological targets [42,43]. Phenolic acids are a subclass of the phenolic compounds that contain at least one aromatic ring and one hydroxyl group (Figure 3). Flavonoids are the largest subclass of polyphenols in the human diet and are characterized by two or more aromatic rings containing at least one hydroxyl group in each and connected with a heterocyclic pyran (Figure 3). Flavonoids can be sub-divided further into two main groups, anthocyanins (glycosylated derivative of anthocyanidin) and anthoxanthins (Figure 3). Anthoxanthins are composed of several categories, such as flavones, flavanones, flavonols, flavanols, isoflavones and their glycosides [44]. It was generally believed that the phenols exerted their health benefit by directly scavenging free radicals or reactive oxygen species (ROS) or chelating of redox metals, but these properties are now largely attributed to the phenols' ability to act as signaling agents of cellular endogenous responses [36,45].

Figure 3. Classification and structure of the main polyphenols classes (adapted from [46,47]).



All plant based systems contain phenolic compounds, but these compounds are typically more diverse and abundant in fruits, vegetables, leaves, and seeds [48]. However, dry beans contain various types and quantities of phenolic compounds depending on the market class [49–53]. As such, different bean market classes can possess different functional food properties. Thompson *et al.* [52] showed that cooked bean powders isolated from different market classes were able to reduce cancer tumors in rats, but the response differed based on the type of bean. The response did not correlate to the amount of total phenols present, but rather to the domestication origin of the bean suggesting that the type or combination of bioactive agents were as important if not more so than the quantity. Moreover, as secondary metabolites, phenols can be impacted by the level of stress (environment, farming practices, production location) potentially altering their phenolic compositional profile on a lot to lot basis [54]. The pinto bean is especially high in the phenols shown in Figure 4 and listed in Table 2 [55,56]. Additionally, dry beans contain lignin, an indigestible component that cross-links with phenolic compounds changing their structure and solubility [57]. Lignins have been shown to promote gastrointestinal health [58]. It also must be noted that dry beans are composed of anti-nutrients (phytates, tannins, lectins, protease, a-amylase inhibitors, saponins, among others), although many have been associated with human health benefits [59]. For example, phytate has been linked to anticancer activity [60], but it also binds cations (*i.e.*, iron and zinc) negatively impacting mineral bioavailability in the intestinal lumen [61].

Figure 4. Structure of pinto based phenols (from ChEBI database [62]).

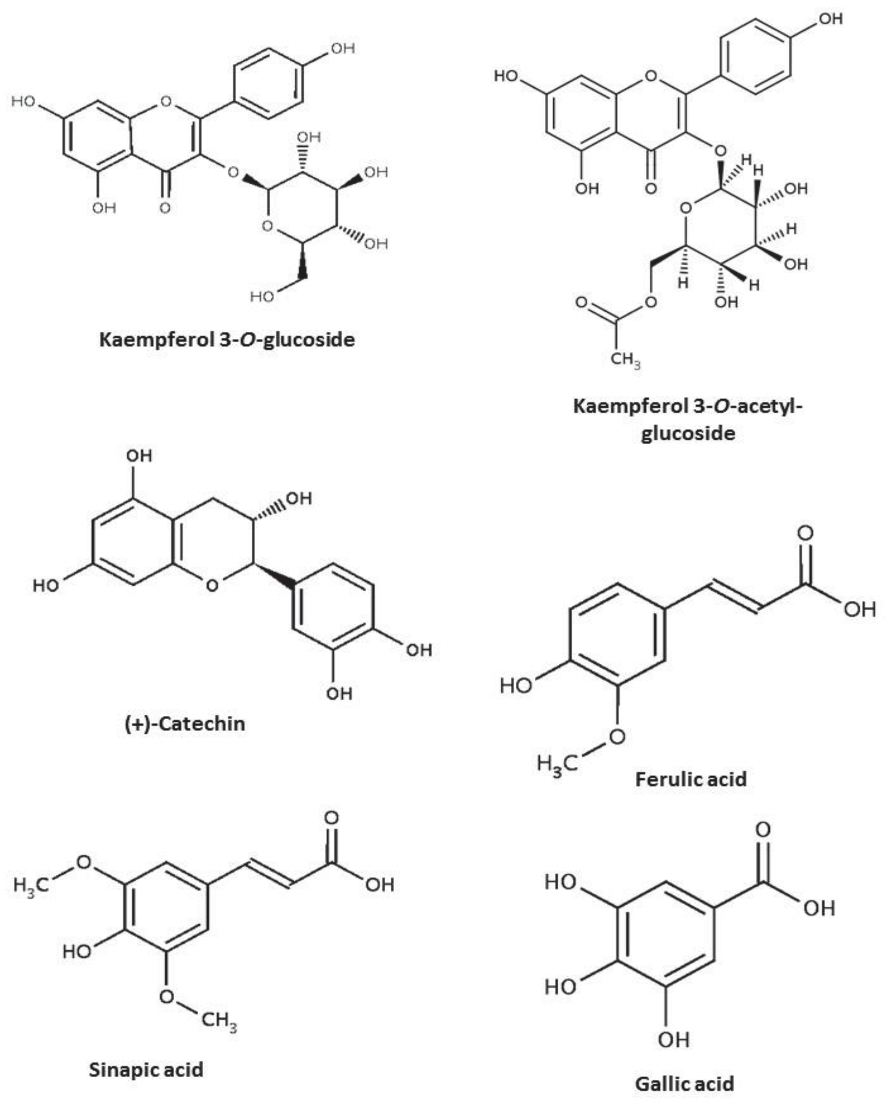


Table 2. Main phenolic compounds present in pinto beans.

Class	Subclass	Content (mg/100g)	Reference
Phenolic acids	p-coumaric acid	4.9 [a]	Luthria & Pastor-Corrales [63]
	Ferulic acid	18.0 [a]	
	Sinapic acid	7.8 [a]	
	Gallic acid	8.7	Xu & Chang [11]
Flavonols	Kaempferol 3-*O*-glucoside	14.8	
	Kaempferol 3-*O*-acetylglucoside	3.0	

[a] mean of three varieties.

4. Functional Food Properties of Pinto Beans: Protection against Chronic Cellular Stresses/Diseases

Chronic conditions such as diabetes, cancer, and heart disease are becoming more prevalent among all ages and ethnic groups throughout the US and other western societies resulting in global economic burdens reaching the $USD trillions [64]. A possible contributor to these debilitating diseases may lie in the consumption of overly processed foods and the high cereal:legume consumption ratio that has emerged in the US over the last 60 years. Instead of the recommended 2 cereal:1 legume ratio for optimal consumption, the ratio has reached 8 or 9:1. Moreover, epidemiology studies have shown positive links between legume (bean) rich diets, such as increased longevity [65], heart health [66,67], and reduced risks for many types of cancers [68–72]. As the pinto bean is the most commonly consumed dry bean in the Americas, this section provides a brief review of the limited but seminal studies on the functional food properties of this market class. A summary of the discussed studies are also shown in Table 3.

4.1. Oxidative Stress

Reactive oxygen species (ROS) and other oxidative agents are produced by physiological and biochemical processes that are critical to human health. Oxidative stress occurs when the production of oxidants is offset by the ability of the cell to readily detoxify these agents. Elevated ROS levels can damage cellular lipids, proteins, and DNA, potentially leading to a variety of chronic conditions or diseases, including CVD and atherosclerosis, hypertension, diabetes and Alzheimer's disease [73,74]. Phenols protect against cellular oxidative caused by inflammation, microbial infection, dietary habits and other effects [75,76] by several possible mechanisms, including scavenging free radicals, inhibiting or activating redox enzymes, or acting as metal chelators [77]. The phenols are typically less potent than pharmaceutical drugs, but most likely exert their long-term physiological effects by their frequent consumption as they are widely distributed in a variety of foods.

Table 3. Summary of studies on pinto beans and health promotion.

Stress-disease	Model	Treatment	Dosage	Main Outcomes	References
Oxidative stress and inflammation	*In vitro* (ORAC, COX and 150 LOX kits)	Hulls extracts from pinto and three types of beans	Pinto beans-158.20 mg/g [a] of total phenols and 3.04 mg/g of flavonols [b]	Total phenolic content and antioxidant activity of bean hulls were 6–8-fold higher than in whole beans. Extracts from pinto beans exhibited highest antioxidant capacity. Black and pinto beans exhibited the strongest COX-1 and COX-2 inhibitory effects. Pinto showed the strongest LOX inhibitory effect.	Oomah *et al.* [56]
Cancer and CVD	40 men and 40 women aged 18–55 y with or without pre MetS	cooked pinto beans	1/2 cup (130 g) of beans per day for 12 weeks	Propionate production was higher in treated groups than in control group. *Eubacterium limosum* was 50% lower in response bean consumption. Beans intake associated with lower blood total cholesterol in the controls (8%) and the pre-MetS group (4%). Bean consumption also resulted in lowered serum HDL-C and LDL-C in both groups.	Finley *et al.* [16]
CVD and diabetes mellitus	mildly insulin resistant adults (7 men, 9 women)	cooked pinto beans	1/2 cup of beans daily for 8 weeks	Reduction of serum TC and LDL-C concentrations by over 8%.	Winham *et al.* [78]
Oxidative stress and bone resorption	12-month-old male C57BL/6 mice	bean hull extract	400 or 800 mg/kg for 3 months	BHE showed high antioxidant activity and its supplementation for 3 months decreased serum concentration of a bone resorption marker, and increased bone mineral density and trabecular thickness in the L3 vertebra in mice.	Cao *et al.* [77]
Colon cancer	5 week old male F344 rats	Cooked pinto beans	Adjusted with beans to 18 g of protein/100 g of diet	Carcinogen azoxymethane induced rats fed a pinto bean rich diet had lower colon adenocarcinoma and tumor multiplicity.	Hughes *et al.* [69]

Table 3. *Cont.*

Stress-disease	Model	Treatment	Dosage	Main outcomes	References
Oxidative stress and cancer cell proliferation	Human gastric adenocarcinoma AGS cells (CAA assay) and 9 human cancer cell lines (anti-proliferation assays)	Phenolic extracts from dry matured seeds of 13 food legumes, including pinto beans	0.125, 0.25, 0.5, 1, 2, and 5 mg/mL of phenolic extract	Pinto beans, lentil and other beans exhibited dose-dependent inhibitory effects on cell proliferation of all tested cancer cell lines. Pinto beans showed the second strongest anti-proliferative activity of all analyzed legumes. Black soybean exhibited the greatest CAA with the lowest IC_{50} value followed by black bean and pinto bean.	Xu & Chang [79]
Oxidative stress and inflammation	macrophage cell line, RAW 264.7	Protein hydrolysates Negro 8025 and Pinto Durango beans	0.5–200 µM (based on soluble protein)	Hydrolysates of both varieties inhibited inflammation by modulation of NF-κB pathways (reducing its transactivation and the nuclear translocation of p65 subunit)	Oseguera-Toledo *et al.* [80]
Cardiovascular health	Normal young men	Canned pinto beans	450 g/day	Average reduction in cholesterol levels (10%).	Shutler *et al.* [81]
Cardiovascular health	Hyperlipidemic men	Whole pinto beans	120–162 g/day	Average reduction in serum cholesterol levels (10.4%).	Anderson *et al.* [82]
Blood glucose levels	*In vitro* digestibility	Pinto Bean Starches	Not applicable	Pinto bean digested at a slower rate compared to faba beans, which may be more effective in controlling glucose levels.	Ambigaipalan *et al.* [83]
Gastrointestinal health	*In vitro* fermentation	Polysaccharides from cooked pinto beans	Not applicable	Higher production of SCFA and altered pH.	Campos-Vega *et al.* [84]

ORAC: oxygen radical absorbance capacity; COX: cyclooxygenase; LOX: lipooxygenase; HDL-C: High density lipoprotein-cholesterol; LDL-C: low density lipoprotein-cholesterol; TC: total cholesterol; BHE: bean hull extract, [a] milligram equivalents of (+)-catechin per gram of sample; [b] milligram equivalents of quercetin per gram of sample. CAA = cellular antioxidant activity; NF-κB: nuclear factor-kappa B; SCFA = short chain fatty acids.

Considering their high phenol content [53,85], the pinto bean as well as other dry beans, probably promotes health in part via antioxidative mechanisms. Xu and Chang [79] reported that black soybean, black bean, and pinto bean exerted the highest antioxidant capacity of the 13 legumes analyzed in the study. Beninger and Hosfield [49] showed that pure flavonoid (anthocyanins, quercetin glycosides, and proanthocyanidins) isolated from 12 different seed coats of dry beans had significant higher antioxidant activity compared to the Fe^{2+} control with the notable exception of kaempferol 3-*O*-glycoside. Using a mice model, Cao *et al.* [77] showed that pinto bean hulls with the highest antioxidative activity positively impacted markers for healthy bone metabolism, *i.e.*, such as decreased bone resorption. It must be noted that the antioxidant capacity of beans can be affected by processing or cooking. Xu and Chang [11] demonstrated that steamed pinto and black beans exerted higher antioxidant activities compared to those boiled in water. These results were attributed to lower losses of total phenols, individual anthocyanins, individual flavan-3-ols, flavonols, and total flavonols to the water.

4.2. Inflammation

Acute inflammation is initiated when infections or tissue damage is recognized by specific receptors in the body [86]. Immune cells migrate to the repair site to combat the infection and repair the damage [87]. During the inflammatory response, multiple chemical mediators are produced and/or activated, including, but limited to, interleukins (IL), nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB), tumor necrosis factor-α (TNF-α), cyclooxygenase (COX), prostaglandin E_2 (PGE_2), inducible nitric oxide synthase (iNOS), and nitric oxide (NO). NF-κB mediates the transcription of many of the pro-inflammatory mediators, including iNOS, COX-2, TNF-α and IL-1β, -6 and -8 [80–82,88–98]. However, if acute inflammation is not stopped, it can progress into self-perpetuating chronic inflammation that can progress into a host of diseases [88]. Chronic inflammation can be sustained by diet, pharmacologic substances, unresolved infections, and environmental pollutants. The drugs used to treat acute inflammation, such as steroidal anti-inflammatory drugs, have not been completely effective against the chronic inflammatory condition and can cause side effects, but food components including vitamins and flavonoids can counteract this effect [74]. Many anti-inflammatory mechanisms have been associated with flavonoids [91–94] (Table 4).

As such, the pinto bean may act as an effective anti-inflammatory functional food again due to its anti-oxidative properties [8]. Oomah, Corbe and Balasubramanian [56] analyzed four types of dry beans, including pinto beans, and reported that the hull extracts were able to inhibit the proinflammatory mediators, COX 1 and COX 2, and lipoxygenase. This effect was attributed to the ability of hull based phenols to stop the formation of inflammatory sustaining ROS. However, the antioxidant activity may not be the only means by which beans stop chronic inflammation. In another study using common beans, Oseguera-Toledo *et al.* [80] assessed the antioxidant capacity and anti-inflammatory properties of protein hydrolysates derived from two bean cultivars, Negro 8025 and Pinto Durango. More specifically, the objective of the study was to evaluate the effect of the bean hydrolysates on NO and PGE_2 production as well as iNOS and COX-2 expression in lipopolysaccaride-induced RAW 264.7 macrophages. The results showed that the hydrolysates of both bean varieties inhibited inflammation by modulating the NF-κB pathway (reducing its transactivation and the nuclear translocation of p65 subunit).

Table 4. Anti-inflammatory mechanisms of flavonoids (adapted from Garcia-Lafuente *et al.* [91]).

Activity	Mechanism	Consequence
Antioxidant activity	- Radical scavenging - ROS generation inhibition - Pro-oxidant enzyme inhibition	Reduction of free radicals and lipid peroxidation
Modulation of inflammatory cells	- Modulation of enzymatic activity - Modulation of secretory processes	Reduction of inflammatory cells activation
Modulation of proinflammatory enzymes	- Inhibition of arachidonic acid enzymes - Inhibition of NO synthase	Reduction of inflammatory mediators (NO, leukotrienes, prostaglandins)
Modulation of proinflammatory mediators	Modulation of cytokine production	Reduction of inflammatory cytokines (TNF-α, interleukins)
Modulation of proinflammatory gene expression	Modulation of signal transduction	Reduction of proinflammatory gene transcription

4.3. Cardiovascular Health

Atherosclerosis is a pathogenic condition caused by accumulating lipids and fibrous compounds in major arteries [95] and is responsible for approximately 50% of reported fatal heart diseases, including CVD [96]. Atherosclerosis is diagnosed by established biomarkers, including total cholesterol (TC), and high ratios low density lipoprotein (LDL) to high density lipoprotein (HDL) levels. As oxidized LDL is a significant contributing factor to atherosclerosis [55], effective treatment include those able to decrease LDL cholesterol (LDL-C) and/or raise HDL cholesterol (HDL-C) in the bloodstream.

Specific studies related to pinto beans and cardiovascular health include research completed by Shutler *et al.* [81]. These researchers showed a 10% reduction in cholesterol levels of normal young males after ingestion of 450 g/d of canned baked beans compared to the group control. Anderson *et al.* [82] also reported a 10% reduction in serum cholesterol levels in hyperlipidemic men fed 120–162 g/d of pinto beans. Other studies that show the positive effects of pinto beans in reducing CVD risk factors on pre metaboloic syndrome subjects are presented in Section 4.4.

Resistant starch is a component of pinto beans that may be partly responsible for the cited effects. The link between RS and blood lipid profiles lies in the production of the short chain fatty acids (SCFA) via RS fermentation by microbes present in the large intestine. In particular, propionate produced by RS fermentation has been correlated with lower blood cholesterol [97]. Furthermore, overall higher levels of SCFA resulting from RS fermentation are a plausible protective property provided by dry bean consumption against CVD [16]. Additionally, beans contain high polyphenols that have shown to protect LDL against oxidation and decrease the uptake and degradation of cell-modified LDL by macrophages [74].

4.4. Metabolic Syndrome

Metabolic syndrome (MetS) is a cluster of metabolic conditions that represent risks for CVD, and Type 2 diabetes [98]. Specific markers of MetS include excess of central adiposity, increased serum triglycerides and LDL-C, lower HDL-C, higher serum glucose, and high blood pressure [16]. Accordingly, pinto beans may protect against MetS symptoms due to the high levels of unabsorbed carbohydrates [7]. For example, the consumption of RS may prevent or remediate MetS by acting on multiple biological targets, such as delaying the delivery of glucose by prolonging tissue absorption, modulating fat utilization, and controlling appetite through increased satiety [99,100]. SCFAs produced from RS fermentation in the GI tract may also alter metabolic pathways affecting blood lipids profiles by inhibiting cholesterol synthesis in the liver or by altering cholesterol usage from the plasma to the liver. Cholesterol synthesis can be suppressed by metabolizing propionate in the liver [100]. Also, GI bacteria can bind bile acids to cholesterol leading to the excretion of bile acid–cholesterol complexes through the feces. Reduced bile acid recycling by the enterohepatic circulation results in cholesterol uptake into the liver for the biosynthesis of bile acids, thereby lowering cholesterol levels and the risk of CVD [101].

Studies cited in Section 4.3 showed the potential of beans in lowering cholesterol levels albeit the subjects were not diagnosed with MetS [81,82]. Alternatively, Finley, Burrell and Reeves [16] determined that human subjects with or without pre-MetS fed 1/2 cup (130 g) of cooked dried pinto beans per day for 12 weeks resulted in different serum lipid profiles. Both groups presented lower serum HDL-C and LDL-C and lower serum total cholesterol, *i.e.*, 8% for the control and 4% for the pre-MetS group control. Also, propionate production was higher in the group fed the pinto beans than the control group. In another study, Winham, Hutchins and Johnston [78] determined whether pinto beans and black eyed peas were able modulate biochemical markers of CVD and diabetes mellitus risks in moderately insulin resistant participants. The results showed decreased serum TC and LDL-C concentrations by over 8% after only 8 weeks of pinto bean consumption. Another study revealed that pinto and black bean starches were able to modulate blood glucose levels more effectively than faba bean starches [83].

Lastly, reduced carbohydrate hydrolysis caused by amylase inhibition can lead to lower postprandial glucose and insulin levels [102]. As in all dry beans, α-amylase inhibitors are high in pinto beans, but the activity is easily destroyed by typical cooking methods [103,104]. Lastly, foods containing low glycemic index carbohydrates, such as pinto beans, may aid in the management of MetS related abnormalities. Such foods are able to moderate blood glucose, blood insulin, and body weight [105], albeit more studies are needed to provide a direct link to pinto beans. Nonetheless, the current studies show the potential of pinto beans as functional food that protects against MetS.

4.5. Cancer

Cancer is a leading cause of death in the US, second only to heart disease, [106], but an estimated one-third of cancer deaths are related to lifestyle that include diet factors [107]. Diets rich in dry beans have been associated with lower risk for cancer as evidenced by several reports but again pinto beans were not typically used [108,109]. One such study showed that laboratory animals fed black or navy beans presented with a 50% reduced incidence and number of colon tumors [68]. In another study using pinto bean [69], rats exposed to the carcinogen azoxymethane (AOM) but fed a bean supplemented diet presented with significantly lower colon cancer compared to the control. In addition Xu and Chang [79] compared the proliferation of nine different cancer cell lines in response to commonly consumed food legumes. The results showed that pinto bean and other type of legumes exhibited a dose-dependent anti-proliferation effect on all the cancer cell lines tested. Importantly, pinto beans presented the second strongest anti-proliferative activity of all analyzed legumes.

The anticancer activity of beans has been mainly attributed to their polyphenolic compounds [60,68,79]. As stated previously, polyphenols are able to protect lipids, proteins, and nucleic acids from ROS that if left unchecked can predispose an individual to cancer [110]. Polyphenols intake has been associated with lower leukocyte immobilization, apoptosis induction, cell proliferation and angiogenesis inhibition [110,111]. Also discussed previously, pinto beans contain high levels of RS that act as substrates for bacterial fermentation that also results in the generation SCFAs [112]. It is the production of these SCFAs that provide the anti-cancer protection, particularly butyrate [113,114]. This SCFA has been associated with growth arrest, apoptosis, and differentiation in several colon cancer cell lines [114].

4.6. Gastrointestinal Health

The symbiotic relationship between human health and the GI environment is currently garnering intense research with diet playing a major role [115–118]. In this capacity, starch and dietary fiber, and the nonstarch polysaccharides (soluble and insoluble, pectins, gums, hemicelluloses, inulin, fructans, stachyose and raffinose) present in pinto beans may impact the GI tract by positively influencing the microbiome and/or its fermentable products [119]. Finley, Burrell and Reeves [16] monitored the resident GI microbiota and SCFA levels in human subjects fed a pinto bean fiber. Although a specific bacterial population was not affected, subjects who consumed the pinto bean flour presented with higher propionate levels compared to the control group who were fed a non-bean soup. Other studies have shown that only minor changes in the GI propionate levels result in lower total cholesterol levels [119,120]. In another study, higher butyrate levels were measured in the hindgut of rats fed a diet supplemented with beans, albeit with red kidney [121]. Considering that the fiber composition between beans classes are similar, comparable results are expected with pinto beans. As noted above, butyrate has been linked to lower risks for cancer [112–114]. Lastly, Campos-Vega *et al.* [84] monitored the production of SCFA generated during the *in vitro* fermentation of polysaccharides obtained from four cooked common bean cultivars, including pinto beans. These results suggest that the dry beans are able to protect the colon by positively altering pH over both short (6 h) and prolonged (24 h) fermentation or transit periods.

5. Conclusions

Dry beans are an important US agricultural crop with our country being a top world-wide producer and distributor, particularly of pinto beans. Moreover, dry beans are an important source of numerous nutrients and phytochemicals that protect against multiple diseases currently afflicting western cultures. Despite their importance, bean consumption is low in the US. This review therefore provides information on dry beans, with an emphasis on the pinto bean, from a historical context, current production and consumption patterns in the United States, their chemical composition, and links to human health benefits. Although our understanding of the latter attributes are increasing, critical gaps in knowledge still remain on the role that pinto beans as any dry beans play in protecting against multiple disease risks or states. As dry beans contain multiple nutrients and other phytochemicals they most likely exert these effects as synergists or additives within the complex bean system, but again research remains limited in this area. Such studies are particularly important considering that dry beans are consumed primarily as whole products or parts of the product while cooking practices can affect their compositional profiles, both chemically and physically, as can the market class, lines, production location, *etc.* However, the existing studies show the potential of pinto beans and other dry bean market classes as a highly effective functional food capable of providing multiple health benefits.

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