Polyphenol-Rich Dry Common Beans and Their Health Benefits

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Polyphenols are plant metabolites with potent anti-oxidant properties, which help to reduce the effects of oxidative stress-induced dreaded diseases. The evidence demonstrated that dietary polyphenols are of emerging increasing scientific interest due to their role in the prevention of degenerative diseases in humans. Possible health beneficial effects of polyphenols are based on the human consumption and their bioavailability. Common beans (*Phaseolus vulgaris* L.) are a greater source of polyphenolic compounds with numerous health promoting properties. Polyphenol-rich dry common beans have potential effects on human health, and possess anti-oxidant, anti-diabetic, anti-obesity, anti-inflammatory and anti-mutagenic and anti-carcinogenic properties.

polyphenols Phaseolus vulgaris anti-oxidants degenerative diseases health-promoting effects

1. Introduction

Plants synthesize secondary metabolites that often have widespread bioactivities, and are known as phytochemicals. Polyphenol is one of the phytochemicals containing large bioactive structural phenolic units. It has a wide range of classification and possesses various pharmacological and health-promoting effects [1]. Polyphenols are largely found in fruits, cereals, vegetables, food legumes, herbs, spices, nuts, wine, olive oil, tea, coffee, and chocolate. Polyphenols are classified into different groups based on the function of several phenyl rings, including flavonoids (flavones, flavonols, flavanones, isoflavones, anthocyanins, chalcones, dihydrochalcones, and catechins), phenolic acids (hydroxybenzoic hydroxyphenyl acetic, hydroxyphenyl pentanoic and hydroxyl cinnamic acids), stilbenes, and lignans [2]. The primary functions of polyphenols are as anti-oxidants involved in the prevention of degenerative diseases such as cancer and metabolic syndromes [2]. The health-promoting effects of polyphenols depend on the quantity consumed in the diet and their bioavailability. In addition, polyphenols are the active substances in many food legumes, which regulate the activity of a broad spectrum of cell receptors, enzymes and gene expression [3]. Animal experimental studies showed that polyphenol in common beans possess anti-oxidant properties and have various biological activities including anti-diabetic, anti-obesity, anti-inflammatory, antimicrobial, anticancer, hepatoprotective, cardioprotective, nephroprotective, neuroprotective, and osteoprotective [4][5][6][7][8][9][10][11].

2. Common Beans and Their Health Benefits

Common beans (*Phaseolus vulgaris* L.) are annual plants, cultivated in temperate and semitropical regions for their edible dry seeds that are variously called navy beans, kidney beans, red beans, black beans, pinto beans, and cranberry beans. They were first cultivated in Peru and Mexico around 8000 years ago and are now cultivated worldwide [12]. They belong to the family Fabaceae. In the temperate regions, the green leaves and immature pods are edible as vegetables. Dry beans are mainly consumed in low- and middle-class families as the large portion of the protein. In many parts of Asian, young leaves are consumed as a salad. The straw of the plant is normally used for fodder after beans are harvested. In 2010, the global production of dried beans was 25.42 million metric tons, and they were harvested on 32 million hectares. About 19.23% of the productions was in India followed by Myanmar (13.88%), Brazil (12.42%), USA (5.66%), China (5.26%), Mexico (4.52%) and Tanzania (4.28%) [12]. The production of dried beans worldwide in 2014 was 27.59 million metric tons, and they were harvested on 31.22 million hectares. About 16.85% of the productions was in Myanmar followed by India (14.89%), Brazil (11.92%), USA (4.74%), Mexico (4.60%), Tanzania (4.023%) and China (3.84%) [12]. Beans are known to be used for treating eczema, diabetes, diuretic, burns, acne, cardiac, bladder, carminative, dropsy, dysentery, emollient, hiccups, itchy, and rheumatism [13].

Common beans do not differ mostly in their nutritional compositions; they differ slightly in taste, texture and cooking times [14]. Navy beans are white in color, and were used in the U.S. Navy diet during the 19th century; hence, their name. They are small-sized, white-skinned, oval-shaped beans. Navy bean-containing diets exerted beneficial effects during experimental colitis by reducing inflammatory biomarkers both locally and systemically [15]. Emerging evidence supports the efficacy of navy beans in regulating serum cholesterol and lipid profiles, and inhibiting the incidence and recurrence of adenomatous polyps or precancerous growths, thereby preventing colorectal cancer [16][17]. Kidney beans are large-sized, firm textured, red/pink glossy skinned and kidney-shaped beans. They have the potential to reduce glycemic index in experimental diabetes [18] and the ability to attenuate colonic inflammation in healthy mice [19]. Red beans are small, soft red textured, oval-shaped beans. They exert an anti-inflammatory response [20] and have health-promoting potential with anti-fungal, immunomodulatory, anti-proliferative and apoptosis-inducing activities in tumor cells [21][22]. Black beans are known as turtle beans, which are sweet in taste, soft texture, medium-sized, and oval-shaped beans. These coats are an excellent source of anthocyanins and other phenolics with the potential to be used as natural food colorants with exceptional anti-diabetic potential [23]. Pinto beans are medium-sized, brown-skinned, oval-shaped beans. Hemagglutinins, defensins isolated from pinto beans, possess anti-fungal, anti-diabetic and anti-tumor activities [24][25]. Cranberry beans, also called Roman beans, are red creamy textured, medium-sized and oval-shaped beans. They are rich in phenolic compounds and non-digestible fermentable components, which may help alleviate experimental colitis and mitigate the severity of other gut barrier-associated pathologies [26].

Common beans play a vital role in the vegetarian diets and provide numerous health benefits connected with eating pattern [27]. They serve as a cost-effective source of nutrients. Health benefits of beans are generally acquired from direct attributes, including their high content of proteins, dietary fibers, low saturated fat content, vitamins, minerals, and phytochemicals, as well as replacement in the diet, when they substitute for animal products [28]. These replacements of meat and other animal products with beans are highly linked with enhanced animal welfare and the decrease in inputs of environmental resources [28]. Sufficient amounts of polyphenols in the

dried beans act as potent anti-oxidants. Regular intake of these dried beans containing total and soluble fiber as well as resistant starches have reduced glycemic index in the human.

3. Nutritional Compositions of Common Beans

Dry common beans (fully matured and dried) are a rich source of proteins, starch, unsaturated fatty acids (linoleic acid), dietary fibers, vitamins and minerals that are considered as important food resources. These dry beans are normally soaked and cooked for few hours, and served as soups, stews, and meat dishes. Green beans (green immature pods) have greater quantities of vitamin C and dietary fiber and are often sold as canned or frozen in the USA, while sold as fresh vegetables in China. Nutritional properties of the beans are highly linked to their measure of protein, and, to a smaller extent, their carbohydrate, vitamin, and mineral contents. The protein present in the bean types is different based on the cultivars, which ranges between 15% and 35%. The predominant amino acids present in the dry beans are lysine (6.5–7.5 g/100 g protein) and tyrosine with phenylalanine (5.0–8.0 g/100 g protein) [29]. Consequently, the protein present in the beans meets the minimal need of human requirements endorsed by the World Health Organization and Food and Agriculture Organization. Thus, 100 g of dry common beans serve in human provides about 9–25 g of protein, which is almost 20% of the recommended daily consumption for a normal adult. In addition, the digestibility of the dry bean protein is almost 80% [30]. About 55–75 g of carbohydrates are present in 100 g of raw beans and predominant fraction in the bean is starch, constituting almost 50% of the seed weight. In addition, dietary fibers (14–19 g/100 g of raw) and oligosaccharides are significant quantities [31]. More than 50% of fibers are insoluble, composed of pectins, pentosans, hemicellulose, cellulose, and lignin. The lipid fraction in the bean is about 1.5–6.5 g in 100 g of raw beans and is mainly composed of mono- and polyunsaturated fatty acids [32].

Dry beans contain biologically active phytochemicals, which are beneficial for human health [3]. While the beans contain huge quantities of protein, it is connected with anti-nutritional factors and other substances that are harmful to human health including polyphenols (including tannins), proteases, lectins, anti-vitamins, galacto-oligosaccharides, flatulence factors, allergens, and phytic acid [33]. Among the anti-nutritional factors, polyphenols are the primary contributors to reduce digestion of the bean in the human. They are highly active and can react with protein to cause impairment of the digestion. Tannins in the beans are potent and have the ability to bind with proteins by H-bonds, and thus prevent their digestion [34]. Boiling bean seeds is the common method of processing, and results in a decrease in the polyphenol content and reduces anti-nutritional factors [35]. The germination mechanism is also improving the levels of free amino acids, nutritional quality, and decreases the anti-nutritional factors [36]. The nutritional compositions of common beans are listed in **Table 1**.

Table 1. Nutritional compositions of common beans in 100 g of edible portion [37][38][39].

Nutrient	Units	Navy Beans	Kidney Beans	Red Beans	Black Beans	Pinto Beans	Cranberry Beans
Energy	kcal	92	92	167	464	500	257
Protein	g	6.15	5.38	22.22	14.29	10.71	22.86
Total lipid (fat)	g	0.00	0.38	0.00	21.43	21.43	0.00
Carbohydrate	g	16.15	20.77	63.89	57.14	60.71	60.00
Total dietary fiber	g	4.6	5.4	44.4	14.3	10.7	25.7
Total sugars	g	0.00	0.77	2.78	3.57	3.57	2.86
Resistant starch	g	4.2	2.0	3.8	1.7	1.9	2.6
Minerals							
Calcium	mg	62	46	167	143	71	114
Iron	mg	1.38	1.38	7.29	3.86	2.57	5.1
Potassium	mg	300	268	222	279	96	265
Magnesium	mg	48	37	44	60	43	39
Sodium	mg	108	8	69	286	286	10
Vitamins							

Nutrient	Units	Navy Beans	Kidney Beans	Red Beans	Black Beans	Pinto Beans	Cranberry Beans
Vitamin C	mg	0.9	0.9	0.0	0.0	0.0	0.0
Folate	µg	127	115	140	128	147	124
Lipids							
Total saturated	g	0.000	0.000	0.000	1.790	1.790	0.000
Total monounsaturated fatty acids	g	0.000	0.000	0.000	14.290	14.290	0.000
Total polyunsaturated fatty acids	g	0.000	0.000	0.000	5.360	5.360	0.000
Polyphenol	mg of gallic acid equiv/g	12.47	14.14	13.68	12.60	12.52	11.73
Flavonoids	mg of rutin equiv/g	1.78	2.59	1.55	1.28	0.98 [40]	1.65

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e phenolic compound is about 145 mg/g and represents about 11% of the total seed [41]. The phenolic compounds in the seeds are flavones, monomers, and oligomers of flavanols, flavanones, isoflavonoids, anthocyanins, chalcones, and dihydrochalcones [40][42][43][44][45]. However, the phenolic acids and non-flavonoid phenolic compounds (hydroxybenzoic and hydroxycinnamic acid) are mainly found in cotyledons of the bean [46]. Based on their chemical structure, they are a highly diverse group ranging from simple molecules such as phenolic acids to complex polymers such as tannins and lignin [47]. The testa of the beans contains greater quantities of proanthocyanidins and anthocyanins [40]. Condensed tannins (10.65 mg catechin equivalents/g) and cyanidin 3-glucoside (3.75 mg catechin equivalents/g) are also mainly present in seed coats of the bean [48][49]. These phenolic compounds are generally varied, based on the seed coat color pattern and types of the cultivar of the beans. The color of the seed coat is based on the presence of polyphenols including anthocyanins, flavonols glucosides, and condensed tannins. Dark-colored beans normally have the highest anthocyanins content [50]. In addition, red, black and pink-colored varieties confer color to the bean seed coat due to their anthocyanins. The colors of light yellow or pink spot of the seed coat are generally based on the presence of condensed tannins [49].

Phenolic compounds isolation and characterization were initiated at early 1960, and four anthocyanin pigments (delphinidin 3-glucoside, petunidin 3-glucoside, malvidin 3-glucoside and 3,5-diglucosides) were extracted from the seed coat of black violet beans [51]. Later, anthocyanins, flavonols, and tannins from the different varieties of kidney beans were isolated and characterized by many researchers [52][53][54][55].

The polyphenols present in the common beans are illustrated in **Table 2**.

Table 2. List of polyphenols in the common beans.

Bean Name	Polyphenol Class	Polyphenol Sub-Class	Compound Name	References
Dark bean	Flavonoids	Anthocyanins	Cyanidin 3-*O*-glucoside, pelargonidin 3-*O*-glucoside, petunidin-3-*O*-*β*-glucopyranoside, malvidin 3-*O*-glucoside, delphinidin acetyl-glucoside, pelargonidin acetyl glucoside, pelargonidin 3-*O*-malonyl glucoside, petunidin feruloyl glucose	[40]
Wild and weedy Mexican bean, pinto and black beans	Flavonoids	Anthocyanins	Peonidin, pelargonidin, cyanidin	[56][57]
Dark bean, Wild, and weedy Mexican bean	Flavonoids	Anthocyanins	Delphinidin 3-*O*-glucoside	[40][56]
Alubia, black, cranberry, dark red kidney, great northern, light red kidney, navy, pink, pinto, and small red	Flavonoids	Anthocyanins	Petunidin 3-*O*-(6″-acetyl-glucoside)	[50][58]

Bean Name	Polyphenol Class	Polyphenol Sub-Class	Compound Name	References
Dark and kidney bean, zolfino landraces	Flavonoids	Anthocyanins	Pelargonidin 3,5-*O*-diglucoside	[40][59]
Alubia, black, cranberry, dark red kidney, great northern, light red kidney, navy, pink, pinto, and small red	Flavonoids	Anthocyanins	Delphinidin 3-*O*-glucosyl-glucoside	[50][60]
Dark bean	Flavonoids	Flavanols	(+)-Catechin, (-)-epicatechin, (+)-gallocatechin, procyanidin dimer, (-)-epigallocatechin, Procyanidin dimer B2, procyanidin dimer B3, procyanidin dimer B4, procyanidin trimer, procyanidin trimer EEC, naringenin 7-glucoside	[40]
Dark bean	Flavonoids	Flavanones	Naringenin, hesperetin, naringin, naringenin 7-*O*-rutinoside, naringenin 7-*O*-glucoside, naringenin-7-methyl ether 2, hesperetin 3′-*O*-glucuronide, hesperetin 7-*O*-glucuronide, hesperetin 3′,7-*O*-diglucuronide, hesperetin 5,7-*O*-diglucuronide, hesperetin 7-*O*-rutinoside	[40]
Dark bean	Flavonoids	Flavones	Apigenin, apigenin 7-*O*-glucoside	[40]
Brazilian bean	Flavonoids	Flavones	Chrysin	[45]
Dark bean, Brazilian bean,	Flavonoids	Flavonols	Kaempferol	[33][40][45]

Bean Name	Polyphenol Class	Polyphenol Sub-Class	Compound Name	References
Mexican bean				
Dark bean, Brazilian bean, Mexican bean	Flavonoids	Flavonols	Quercetin	[33][40][45]
Dark bean, and Brazilian bean	Flavonoids	Flavonols	Quercetin 3-*O*-galactoside, Quercetin 3-*O*-glucoside, Quercetin 3-*O*-rutinoside, Myricetin, Myricetin 3-*O*-glucoside, Myricetin 3-*O*-rhamnoside, Kaempferol 3-*O*-glucoside, Kaempferol 3-*O*-rutinoside	[40][45]
Pinto beans, zolfino landraces	Flavonoids	Flavonols	Kaempferol 3-*O*-glucosylxylose	[42][61]
Alubia, black, cranberry, dark red kidney, great northern, light red kidney, navy, pink, pinto, and small red	Flavonoids	Flavonols	Kaempferol 3-*O*-xylosyl-glucoside	[50][58]
Pinto beans	Flavonoids	Flavonols	Kaempferol 3-*O*-acetyl-glucoside	[42]
Dark bean, Brazilian bean	Flavonoids	Isoflavonoids	Daidzein	[40][45]
Dark bean, Brazilian bean	Flavonoids	Isoflavonoids	Genistein	[40][45]

Bean Name	Polyphenol Class	Polyphenol Sub-Class	Compound Name	References
Dark bean	Flavonoids	Isoflavonoids	Biochanin A	[40]
Pinto and black beans	Flavonoids	Isoflavonoids	Glycitein	[57]
Dark bean	Flavonoids	Isoflavonoids	Dihydrogenistein	[40]
Brazilian bean	Polyphenols	Polyphenols	Coumestrol	[45]
Dark bean, pinto and black beans, Mexican bean	Phenolic acids	Hydroxybenzoic acids	Protocatechuic acid	[33][40][57]
Dark bean	Phenolic acids	Hydroxybenzoic acids	Gallic acid	[40]
Mexican bean	Phenolic acids	Hydroxybenzoic acids	Vanillic acid	[33]
Dark bean, Mexican bean	Phenolic acids	Hydroxycinnamic acids	*p*-Coumaric acid	[33][40][60][62]
Pinto and black beans	Phenolic acids	Hydroxycinnamic acids	Caffeic acid [63]	[57]
Dark bean, Mexican bean	Phenolic acids	Hydroxycinnamic acids	Ferulic acid	[33][40]
Dark bean	Phenolic acids	Hydroxycinnamic acids	Sinapic acid, Ferulic acid 4-glucoside	[40]

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Bean Name	Polyphenol Class	Polyphenol Sub-Class	Compound Name	References
Dark bean	Stilbenes	Stilbenes	*trans*-Resveratrol, resveratrol 3-*O*-glucoside	[40]

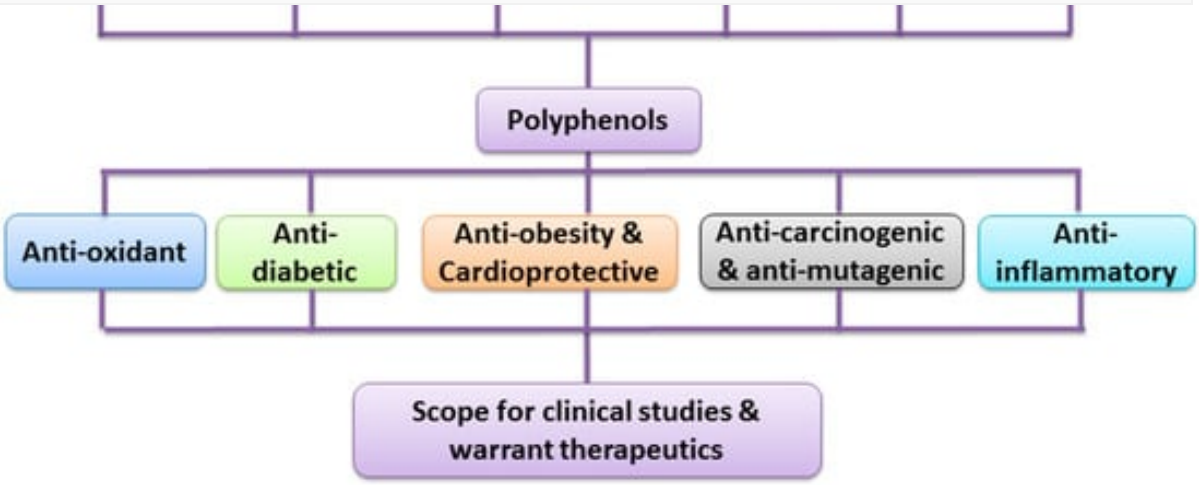

Figure 1. Health promoting effects of polyphenol-rich dry common beans.

5.1. Anti-Oxidant Activity

The dry common beans have excellent anti-oxidant activities because of its phenolic acids, flavonoids, stilbenes, and tannins. These anti-oxidant activities are primarily due to the reducing capacity of polyphenols as they play vital functions in neutralizing free radicals and scavenging radicals or suppressing lipid peroxidation [64]. In addition, polyphenols involve chelation of metal ions, causing impairment/cessation of oxidative mechanisms. Generally, the anti-oxidant activity is elevated during digestion and absorption of the common beans in the intestine. Normally, phenolic compounds are released higher in the stomach due to its acidic environment, and the acid medium and enzyme-mediated hydrolysis facilitate the higher solubility of polyphenols along with starch and proteins [44]. Common beans containing polyphenols have demonstrated the highest total anti-oxidant capacity measured by in vitro methods of 2,2'-Diphenyl-1-picrylhydrazyl (DPPH), β-carotene bleaching, ferric reducing anti-oxidant power, oxygen radical absorbing capacity, Trolox equivalent anti-oxidant capacity, and total radical-trapping anti-oxidant parameters [42][43][57][65][66][67][68][69].

5.2. Anti-Diabetic Activity

Venn and Mann [70] have strongly suggested that the regular consumption of dry common beans is beneficial in the prevention and management of diabetes. Clinical studies show that consumption of three or more servings of beans in a week decreases the menace of diabetes almost by 35%, as compared to less or non-consumption of beans [71]. In vitro anti-diabetic studies of common beans have showed a greater inhibition of *α*-amylase, α-glucosidase and dipeptidyl peptidase-IV, which have found to be anti-hyperglycemic activities due to their phenolic

compounds such as flavonoids and their glucosides of delphinidin, petunidin, and malvidin, anthocyanins, catechin, myricetin 3-*O*-arabinoside, epicatechin, vanillic acid, syringic acid, and *O*-coumaric acid [23][72][73][74].

5.3. Anti-Obesity and Cardioprotective Activity

Metabolic syndrome is the set of metabolic conditions connected with the threat of cardiovascular diseases, increased triglycerides (TG), total cholesterol (TC), low density lipoprotein (LDL), very low density lipoprotein (VLDL), blood pressure (BP), and glucose as well as lower levels of HDL and central adiposity [75][76]. Regular intake of dry common beans has proven to be favorable for healthy subjects as well as obese individuals by decreasing serum TC and LDL and elevating HDL [77]. Epidemiological and clinical studies have demonstrated that consumption of common beans inversely connected with the risk of cardiovascular and coronary arterial diseases [76][78]. Further, these studies revealed that consumption of beans four or more times per week reduced the risks of coronary arterial diseases (22%) and cardiovascular diseases (11%): serum TC declines of about 1% decrease the risk of coronary heart disease by 2%, while serum LDL declines of about 1% reduce the risk of both diseases by about 1% [78]. Two weeks of regular consumption of baked beans by hypercholesterolemic individuals showed a significant reduction of TC (12%) and LDL (15%) [79].

5.4. Anti-Mutagenic and Anti-Carcinogenic Activities

Normally, the generation of ROS and oxidative stress damage macromolecules such as lipid, protein RNA, and DNA, which may cause chronic degenerative diseases, including cancer [80][81]. However, the occurrence of cancer can be decreased by lifestyle and dietary habit changes. Studies have also suggested that diets rich in common beans reduce the greater risk of various cancers including colon, breast, and prostate [82][83][84]. A larger study conducted in 41 countries found that the consumption of common beans reduced the morbidity by cancers such as colon, breast, and prostate [85]. Further, studies have revealed that consumption of beans two or more times per week reduced the risks of colon cancer up to 47% [86], prostate cancer about 22% [87] and breast cancer about 67% [88]. In vivo studies have also suggested consumption of beans reduced risk of various cancers [83][89][90][91][92].

5.5. Anti-Inflammatory Activity

Common beans contain phenolic compounds (phenolic acids, flavonoids, and anthocyanins) and non-digestible fermentable components (short-chain fatty acid precursors) with demonstrated anti-oxidant and anti-inflammatory activities. Experimental studies associated with modulation of inflammatory-related cell signaling pathways by common beans have been well established. In an animal study, C57BL/6 mice fed a 20% navy bean or black bean flour-containing diet showed significantly reduced dextran sodium sulfate induced experimental colitis and inflammation-related parameters (IL-1β, TNFα, IFNγ, IL-17A, and IL-9), increased histological injury score and apoptosis, and alleviated symptoms of colitis and colon inflammation [15]. Common beans possess various bioactive compounds including flavonoids and anthocyanins, which significantly reduced the activity of murine macrophages through the inhibition of pro-inflammatory gene expression without cytotoxicity [93][94][95]. Similarly, human-randomized, controlled, crossover trials have also demonstrated that three-day intake of 100 g of black bean meal and soup improved the arthritic condition by significantly reducing pain and inflammation [95]. The

immunomodulatory effects of 20% navy bean or black bean or cranberry bean administration in C57BL/6 mice for two weeks showed a significant reduction in colonic mucosal damage and inflammation in response to dextran sodium sulfate. The results further demonstrated that common bean containing bioactive compounds including phenolic acids, flavonoids, and anthocyanins provoke prominent immune response [26][96].

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