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REVIEW ARTICLE

Bioactive constituents in pulses and their health benefits

Balwinder Singh[1] · Jatinder Pal Singh[2] · Khetan Shevkani[2,3] · Narpinder Singh[2] · Amritpal Kaur[2]

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Abstract Pulses are good sources of bioactive compounds such as polyphenols, phytosterols and non-digestible carbohydrates that play important physiological as well as metabolic roles. These compounds vary in concentration amongst different pulse species and varieties. Pulse seed coats are rich in water-insoluble fibres and polyphenols (having high antioxidant activities), while cotyledons contain higher soluble fibres, oligosaccharides, slowly digestible and resistant starch content. Ferulic acid is the most abundant phenolic acid present in pulses, while flavonol glycosides, anthocyanins and tannins are responsible for the seed coat colour. Sitosterol (most abundant), stigmasterol, and campesterol are the major phytosterols present in pulses. Pulse fibres, resistant starch and oligosaccharides function as probiotics and possess several other health benefits such as anti-inflammatory, anti-tumour, and reduce glucose as well as lipid levels. Beans and peas contain higher amounts of oligosaccharides than other pulses. Processing methods affect resistant starch, polyphenol composition and generally increase antioxidant activities of different pulses. In this review, the current information on pulse polyphenols, phytosterols, resistant starch, dietary fibre, oligosaccharides, antioxidant and associated health benefits are discussed.

Keywords Pulses · Polyphenols · Phytosterols · Resistant starch · Dietary fibre

Introduction

Pulses are annually grown leguminous crops that yield one to twelve grains/seeds within a pod, and are often promoted in diet owing to their low cost and many beneficial nutritional effects (Craig 2009). The United Nations general assembly has declared 2016 as the international year of pulses (Oyeyinka et al. 2016). The Food and Agriculture Organization (FAO) describes pulses as the crops that are harvested only for dry grain. This definition excludes crops that are harvested green as food sources (such as green beans and green peas), crops that are used only for sowing purposes (such as alfalfa and clover) and crops used primarily for oil extraction (such as peanuts and soybean). India is the largest producer (around 25 %) of pulses in the world and the Indian subcontinent covers the leading area in terms of consumption of pulses. It was also suggested that India can also increase the production output by 30 %, considering a rise in government support prices for stimulating the growth of pulses and in case of a normal monsoon season (FAOSTAT 2008). The mainly grown pulses in India include mungbean (green gram), chickpea (Bengal gram), urd bean (black gram), lentil (masur), pigeon pea (arhar), cowpea, horse gram and peas (Tiwari and Singh 2012). In the western countries, nowadays pulses are one of the preferred food sources of the population, owing to ideological reasons and interest in vegetarian diet.

Pulses are rich in macronutrients such as proteins (usually 21–26 %), carbohydrates and are low in calories and fat (Marinangeli and Jones 2011). Pulse proteins can be used in gluten-free products, including muffins and edible

✉ Amritpal Kaur
amritft33@yahoo.co.in

[1] Department of Biotechnology, Khalsa College, Amritsar, Punjab 143002, India

[2] Department of Food Science and Technology, Guru Nanak Dev University, Amritsar, Punjab 143005, India

[3] Centre for Applied Agriculture, Central University of Punjab, Bathinda 151001, India

biodegradable films (Shevkani and Singh 2014; Shevkani and Singh 2015). Although historically the general health benefits of pulses have been associated with these macronutrients, yet nowadays there are sufficient evidences that suggest some non-nutritional compounds present in them also play a significant role in the maintenance of human health. Bioactive compounds are usually the non-nutrient food constituents that typically occur in small quantities (when compared with macronutrients) in cereals, legumes and fruits as well as vegetables. Pulses contain plenty of bioactive substances that are not considered as nutrients, but otherwise exert metabolic effects on human body upon consumption (Rochfort and Panozzo 2007). Some of these substances play important role in defense mechanisms of the plants against environmental conditions or predators, while others act as reserve compounds that are accumulated (mainly for germination) in seeds as energy stores. These bioactive components include dietary fibres, resistant starches and bioactive phytochemicals (mainly polyphenols and phytosterols) which make pulses suitable for application in wide range of food products. Other bioactive components include phytates, lectins and enzyme inhibitors that are often considered as anti-nutritional factors. In spite of this, these compounds are mainly concentrated in the hull portions of the pulses and have been hypothesised to prevent many diseases (Kabagambe et al. 2005). Dehulling is a good alternative for utilizing seed coats for specialized phytochemicals in designing of nutraceuticals, while cotyledons can be used as a vegetable protein sources.

The present research is focusing on replacing energy dense foods with pulses as it has shown to have beneficial effects not only on the management, but also prevention of obesity and other related disorders (Rebello et al. 2014). Polyphenols from pulses are of particular interest as these not only contribute to the seed colour as well as sensory characteristics, but also provide several biological properties including antioxidant, anti-inflammatory, anti-artherogenic and antimicrobial effects (Balasundram et al. 2006). Moreover, phytosterols have emerged as valuable nutraceuticals and functional foods in the market. These compounds are essential components of the lipid membrane bilayer in all plant tissues and show antibacterial, anti-inflammatory, antitumor and anti-ulcerative properties (Uddin et al. 2015). Dietary fibre (8–28 % in concentration) as a bioactive component of pulses is another area of interest, which depends on the variety, species and processing methods used. Moreover, other non-nutritional substances in pulses can potentially have beneficial effects in physiological conditions, but the safe as well as the minimum concentrations of these compounds required for the desirable effects need to be determined and afterwards optimized. Therefore, the aim of this review is to provide the current knowledge of certain classes of bioactive compounds present in pulses including polyphenols, phytosterols, resistant starch, dietary fibre and oligosaccharides. Additionally, the antioxidant activity and human health benefits of these metabolites are also discussed.

Polyphenols

Polyphenols have an aromatic ring that bears one or more than one hydroxyl substituents that range from simple to highly polymers compounds (Singh et al. 2015). These compounds are bioactive secondary metabolites widely distributed in all higher plants and are mainly synthesized by the shikimic acid pathway. These phytochemicals are generally categorized into four major groups that include flavonoids, phenolic acids, lignans and stilbenes (Singh et al. 2016c). Bioactive compounds such as polyphenols have a wide therapeutic potential as these can contribute towards the antioxidant activities (Singh et al. 2016a). Phenolic acids and their derivatives flavanols, flavan-3-ols, anthocyanins, condensed tannins are the main polyphenol categories present in legume seeds. Flavonoids, phenolic acids and procyanidins are the dominant phenolic compounds present in lentils, peas and common beans (Zhang et al. 2015). Dehulling of pulses results in removal of large amounts of polyphenols as these are concentrated in the seed coat portions. Girish et al. (2012) reported that about one-fourth of the black gram grain was removed as a by-product after milling process which includes the seed coat rich in polyphenols.

Seed coat of legumes acts as a protective barrier for the cotyledon and it contains high concentration of phenolic compounds (Dueñas et al. 2006). The polyphenols are mainly present in the seed coat portions of beans, while cotyledons contain relatively lower amounts. Flavonol glycosides, anthocyanins and tannins were reported to be responsible for the seed coat colour in dry beans. The amounts of cyanidin 3,5-diglucoside, cyanidin 3-glucoside, delphinidin 3-glucoside, petunidin 3-glucoside, pelargonidin 3-glucoside in seed coats of kidney beans were in the ranges of 0–0.04, 0–0.12, 0–2.61, 0–0.17 and 0–0.59 mg/g dry weight [DW] (Choung et al. 2003). Phenolic and tannin contents of four common beans having different seed coat colors were reported to vary significantly (Madhujith et al. 2004). Red, brown and black bean extract contained high polyphenol and tannin content, while white whole bean extract had the lowest amount. Total phenolic content (TPC) varying from 11.2 to 25.3 mg catechin (CE) equivalents/g DW has been reported for cotyledons of seven bean cultivars (Rocha-Guzmán et al. 2007). Luthria and Pastor-Corrales (2006) separated and quantified phenolic acids present in fifteen dry bean varieties using high performance liquid chromatography (HPLC). They detected and quantified ferulic acid (which was also the most abundant), p-sinapic acid and coumaric acid in all of the varieties, while caffeic acid was only detected in two black bean varieties. Lin et al. (2008) reported that hydroxycinnamic acids were similar for commercial bean varieties, but the flavonoid components showed distinct differences. Moreover, black beans were observed to contain primarily 3-O-glucosides of malvidin, petunidin and delphinidin, whereas the main flavonoids in kidney beans were diglycosides of quercetin and kaempferol. Bean coats have a relatively higher level of TPC and flavonoids than most cereal grains and are potential candidates to be used as food preservatives. Jin et al. (2012) characterized proanthocyanidins (oligomeric and polymeric polymeric flavonoids) in lentil, pea and faba bean seeds. In peas, the proanthocyanidin subunit composition was mainly prodelphinidin (gallocatechin and epigallocatechin), while procyanidin- and prodelphinidin-type flavan-3-ol subunits were the main proanthocyanidins of faba beans and lentils.

Aguilera et al. (2011) investigated phenolic profile of Cannellini and Pinta bean flours as well as foods that were bean-based. Several phenolic compounds, non-flavonoids (such as hydroxybenzoic and hydroxycinnamic acids) and flavonoids were identified in the study. The seed coat of lentils was reported to be rich with catechins and procyanidins dimers, while myricetin, quercetin, apigenin and luteolin glycosides are presented in minor concentrations (Dueñas et al. 2006). On the other hand, the cotyledons mainly contain hydroxybenzoic and hydroxycinnamic acids (Dueñas et al. 2006). Han and Baik (2006) reported that TPC of lentils was much higher than that of chickpeas and yellow peas. Amarowicz et al. (2010) identified twenty polyphenolic compounds in the crude extracts of lentils which included flavonols, hydroxycinnamates, procyanidins, dihydrochalcones, dihydroflavonols and gallates using HPLC-PAD and HPLC–MS techniques. Dueñas et al. (2014) elucidated specific polyphenols present in the seed coat and cotyledons of 2 varieties of dark peas using HPLC-PAD-MS. Quercetin, luteolin and apigenin, proanthocyanidins, flavones, flavonol glycosides and trans-resveratrol-3-glucoside were found in the seed coat. The cotyledon contained hydroxybenzoic, hydroxycinnamic, trans pcoumaroyl-malic acid and p-hydroxybenzoyl-malic acid. Mirali et al. (2014) successfully applied HPLC–MS method for analyzing polyphenols from seed coats (green, black and grey) of three lentil genotypes. They reported that amounts of oligomeric flavan-3-ols were almost similar for all the three genotypes, while luteolin as well as its glycosylated form were present in more amounts in the black seed coat genotype. Zhang et al. (2015) identified twenty-one phenolic compounds (with the majority being flavonoids including catechin glucosides, procyanidins and kaempeferol glycosides) from twenty Canadian lentil cultivars (green and red).

Lentil seed coat contains more abundant and diverse type of polyphenols as compared to cotyledon. Different sub-classes (6 in total) of phenolic compounds were found in the seed coat and they mostly consist of oligomers and polymers of proanthocyanidins (Mirali et al. 2014). Phenolic acids, flavan-3-ols, proanthocyanidins, anthocyanidins, stilbenes, flavonols, flavones and flavanones are the major polyphenols identified in lentil seeds (Alshikh et al. 2015). TPC in free, esterified and insoluble forms were reported in the range of 1.37–5.53, 2.32–21.54 and 2.55–17.51 mg GAE/g of defatted lentil samples, respectively (Alshikh et al. 2015). Free and esterified flavonoids in lentils were observed in the range of 0.01–0.80 and 0.36–4.13 mg catechin eq/g defatted sample, respectively. Aguilera et al. (2011) identified 35 phenolic compounds in raw and processed lentil flours. The identified phenolic compounds were catechins and procyanidins (69 %), flavonols (17 %), flavones and flavanones (5 %), hydroxybenzoic (5 %) and hydroxycinnamic compounds (4 %). High concentrations of flavonoids were reported in the seed coat of lentils. López-Amorós et al. (2006) determined phenolic compounds in raw pea and reported the concentration (µg/100 g DW) of protocatechuic acid (206–221), p-hydroxybenzoic acid (11.9–13.7), vanillic acid (31.2–34.4), trans p -coumaric acid (37.7–41.5), cis p-coumaric acid (65.5–70.1), cis p-coumaric acid derivative (31.9–33.7) and trans ferulic acid (9.9–10.9). Parmar et al. (2016) reported that ferulic acid was the main compound in raw grains of various pulses. Moreover, they reported that raw kidney beans had a greater accumulation of chlorogenic acid, catechin, ferulic acid and p-coumaric acid than field pea and chickpea.

TPC in hull, whole, and dehulled dry beans was observed in the range of 2.2–78.2 mg CE/g with most of phenolics are concentrated in the hull portion (56 mg CE/g) of beans (Cardador-Martinez et al. 2002). TPC in the crude extracts of adzuki bean, green lentil, red lentil, red bean and pea was 90, 68, 58, 55 and 23 mg GAE (gallic acid equivalents)/g DW, respectively (Amarowicz et al. 2010). Total flavonoid content in seeds of pea, chickpea, lentil, red kidney and black bean was in the range of 0.08–3.21 mg CAE/g DW (Xu et al. 2007). Lentils (47.6 mg/g DW) and kidney beans (45.7 mg/g DW) had the highest phenolic content and baby lima bean had the lowest (9.5 mg/g DW). The content of catechin, procyanidin B2, B3 and procyanidin tetramer in raw lentils was in the range of 0.1–0.5 mg/100 g DW (López-Amorós et al. 2006). Sharma et al. (2015) reported an average phenolic content of 78.9 mg GAE/g for field pea. Parmar et al. (2014) documented that dark coloured kidney beans had more TPC than light coloured beans (ranging from 0.1 to 7.1 mg GAE/g DW). Segev et al. (2010) reported that coloured chickpea seeds contained up to 13 and 31 fold more TPC and antioxidant activity, respectively, than beige and regular cream coloured seeds, indicating their use as potential functional foods. Campos-Vega et al. (2010) reported that chickpeas had varying amounts of genistein, formononetin and daidzein (0.06, 0.14 and 0.04 mg/100 g DW), respectively.

Phytosterols

Phytosterols are the plant sterols having a structure similar to cholesterol. These compounds are extensively studied as functional food ingredients and well known for their wide variety of health benefits such as lowering of blood cholesterol levels and reducing the intestinal absorption of dietary and endogenous cholesterol. Phytosterols are not synthesized in our body and are taken from the diet by intestinal absorption. These bind with bile acids and prevent their reabsorption. Studies have indicated that pulses have good amount of phytosterols (as a component of plant cell membranes). These bioactive compounds are found in seeds of many legumes like chickpeas, beans, peas, lentils and lupins (Table 1). Phytosterol concentration in kidney beans and chickpeas was reported to be 127 and 35 mg/100 g, respectively (Weihrauch and Gardner 1978). Ryan et al. (2007) studied the total phytosterol content in butter beans, chickpeas, kidney beans, lentils and peas and reported it in the range of 134 mg/100 g DW (kidney beans) to 242 mg/100 g DW (peas). In addition, chickpeas and lentils had a phytosterol content of 205 and 158 mg/100 g DW, respectively. They further measured the β-sitosterol, campesterol, stigmasterol content and reported that the β-sitosterol was the dominant phytosterol in all the studied legumes. Pulses mainly contain phytosterols in range of 124–135 mg/100 g DW (Weihrauch and Gardner 1978). The phytosterol profile of cooked dry beans, chickpeas and peas were studied by Kalogeropoulos et al. (2010). β-sitosterol, campesterol, stigmasterol and Δ^5-avenasterol were found in cooked dry legumes. β-sitosterol was predominant in all pulses with its highest concentration in chickpeas (38.52 mg/100 g DW). Their study showed that cooking caused a reduction in phytosterol levels of legumes.

Pulses have a high percentage of glycosylated sterols. Nyström et al. (2012) studied the contents of total sterols and glycosylated sterols in adzukibeans, black beans, black eye beans, red beans, white beans, chickpeas and lentils. Sitosterol, stigmasterol, and campesterol are the common sterols present in these pulses. Lentil contains a high proportion of sitosterol and low proportion of stigmasterol, whereas it is opposite in case of beans. Nyström et al. (2012) reported that most of the beans and lentils had glycosylated sterols ranging between 100 and 150 mg/g DW. Phytosterols in pulses occur in the form of free sterols, acylated steryl glycosides and steryl glycosides. Phytosterols from black bean seed coats were identified and quantified in free and conjugated forms by Chávez-Santoscoy et al. (2014). They identified stigmasterol (as free); campesterol (as free), acylated steryl glycoside and steryl glycoside forms; sitosterol (both free and as acylated steryl glycoside); and Δ^5-avenasterol (as free and steryl glycoside forms). They further reported that the most abundant free phytosterols found in the black bean seed coat extract was sitosterol. Iriti et al. (2009) documented that sitosterol was the major phytosterols component found in beans (27.2 mg/100 g DW). These studies indicated that lentils, chickpeas, beans and peas are the main source of phytosterols among pulses.

Bioactive carbohydrates

Carbohydrates form major portion of pulses accounting to as high as 70 % of seeds. Based on the nutritional and physiological roles, these are classified into available (hydrolyzed by gastrointestinal enzymes, absorbed and metabolised by the body) and unavailable carbohydrates (not hydrolyzed by the enzymes and pass into the large intestine). The lower glycemic index (GI) of pulses (slow break down of carbohydrate and slow release of glucose into the bloodstream) is attributed to higher contents of indigestible/unavailable carbohydrates such as dietary fibres, resistant/indigestible starch and some oligosaccharides. These collectively stimulate the activity of prebiotics (*bifidobacteria* and *lactobacilli*) in the colon, resulting in increased production of short chain fatty acids (SCFA; mainly acetic, propionic and butyric acids) along with organic acids (mainly lactic, succinic and pyruvic) and gases (CH_4, CO_2, and H_2), conferring various health benefits to humans. The SCFA are the preferred respiratory fuel for the cells of colon lining and further contribute to increase colonic blood flow, maintenance of low pH, and prevention of abnormal colonic cell growth (Nugent 2005). The indigestible fractions from black bean and lentil were observed to be the best substrate for the production of SCFA (particularly butyric acid) by Hernández-Salazar et al. (2010).

Dietary fibre

Dietary fibres are regarded as one of the most important bioactive constituents of pulses. There are several definitions of dietary fibre some include starch polysaccharides while others do not. Tharanathan and Mahadevamma

Table 1 Phytosterol content in some pulses

Pulses	Total phytosterol content (mg/100 g)	β-Sitosterol	Level of phytosterols (mg/100 g)		
			Campesterol	Stigmasterol	Δ^5-Avenasterol
(i) Beans					
Broad beans[a]	35.1	28.6 ± 1.7	2.92 ± 0.32	1.13 ± 0.10	2.44 ± 0.38
Butter beans[b]	186	85.1 ± 7.3	15.2 ± 2.9	86.2 ± 5.7	–
Kidney beans[b]	134	86.5 ± 2.6	6.5 ± 0.8	41.4 ± 1.6	–
Kidney beans[c]	127	–	–	–	–
Pinto bean[a]	21.5	12.5 ± 0.9	1.75 ± 0.11	4.82 ± 0.43	2.44 ± 0.17
Black eye bean[a]	13.5	6.7 ± 0.3	1.19 ± 0.11	3.84 ± 0.31	1.78 ± 0.18
Black bean seed coats[d]	146	70.65 ± 1.51	66.71 ± 1.99	3.21 ± 0.13	5.50 ± 0.51
(ii) Lentils					
Large lentils[a]	31.6	24.2 ± 1.0	2.18 ± 0.24	2.63 ± 0.18	2.52 ± 0.23
Small lentils[a]	22.9	15.4 ± 1.5	2.58 ± 0.24	2.60 ± 0.15	2.33 ± 0.14
Lentils[b]	158	123.4 ± 4.1	15.0 ± 0.4	20.1 ± 0.6	–
(iii) Chickpeas					
Chickpeas[a]	48.9	38.5 ± 3.1	4.32 ± 0.35	2.45 ± 0.27	3.58 ± 0.29
Chickpeas[b]	205	159.8 ± 7.1	21.4 ± 0.7	23.4 ± 0.7	–
Chickpeas[c]	35	–	–	–	–
(iv) Pea					
Yellow split peas[a]	42.8	37.2 ± 2.6	2.33 ± 0.30	1.12 ± 0.12	2.16 ± 0.24
Green split peas[a]	33.7	27.9 ± 2.0	2.40 ± 0.31	1.51 ± 0.18	1.88 ± 0.13
Pea[b]	242	191.4 ± 0.4	25.0 ± 6.9	26.0 ± 0.6	–
(v) Lupin					
Lupines[a]	53.6	30.9 ± 1.5	11.9 ± 1.1	4.98 ± 0.45	5.89 ± 0.47

[a] Kalogeropoulos et al. (2010): Content in cooked pulses, Levels are the mean ± standard deviation of three analyses

[b] Ryan et al. (2007): Content in uncooked pulses, Levels are the mean ± standard error of three analyses

[c] Weihrauch and Gardner (1978): Content in raw pulses

[d] Chávez-Santoscoy et al. (2014) content in seed coat extract, Levels are the mean ± standard error of three analyses

(2003) described dietary fibres as the macromolecules that cannot be digested by human endogenous enzymes and are essentially composed of plant cell wall components. According to the American Association of Cereal Chemists International (AACCI) dietary fibre is the edible part of plants and analogous carbohydrates that resist the digestion and absorption processes in the human small intestine with partial or complete fermentation in the large one (Rebello et al. 2014). Therefore, dietary fibres do not constitute a defined chemical group but represent a combination of heterogeneous substances viz. cellulose, hemicelluloses, gums, pectins, mucilages, β-glucans, lignins, resistant starch, non-digestible oligosaccharides, and other associated plant substances. The dietary fibres are classified into soluble and insoluble dietary fibres (SDF and IDF, respectively) based on their solubility in water and buffer systems. Both seed coat and cotyledon are fibre rich parts of pulse seeds (Parihar et al. 2016). The seed coat is rich in water-insoluble polysaccharides, primarily cellulose, whereas the cotyledon fibre comprises of hemicelluloses, pectins and cellulose having varying degrees of solubility. Pulses are good source of dietary fibre and contain both SDF and IDF, the later being the major portion of pulse dietary fibres (Wang and Toews 2011). Pulse SDF constitutes gums, pectins, fructans, inulins, and some hemicelluloses, whereas IDF included cellulose, some hemicelluloses, lignins, and arabinoxylan (Rebello et al. 2014). The total dietary fibre (TDF) content of different pulses (beans, chickpeas, lentils, and peas) ranged from 14 to 32 %, with SDF and IDF ranging from 0–9 and 10–28 %, respectively against 3.00–15.02, 0.86–4.33, and 2.14–10.79 %, respectively for cereals like wheat, rice and barley (Yadav et al. 2010a; Rebello et al. 2014; Dueñas et al. 2016).

The interaction of fibres with other bioactive constituents e.g. polyphenol also influences the physiological properties and health benefits of dietary fibres. The pulse fibres can interact with the polyphenolic compounds present in pulses through the formation of hydrogen and hydrophobic linkages between polyphenols and cell wall components. The fibres from beans and lentils were reported to contain associated hydroxybenzoic and hydroxycinnamic compounds, flavan-3-ols, procyanidins, flavonols and flavones, wherein IDF contain more associated phenolic compounds than SDF (Dueñas et al. 2016).

Resistant starch

Starch, a storage carbohydrate, constitutes a major proportion (45–65 % of dry matter and 70–75 % of total carbohydrates) of almost all pulses. Although it is the primary available carbohydrate in pulses, not all of it is digested and metabolised in the body. Based on the rate of enzymatic digestion, glucose release, and absorption in the gastrointestinal tract, starches are classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Englyst et al. 1992). RDS is rapidly and completely hydrolyzed in the small intestine and is associated with high risk of type-2 diabetes and obesity. SDS is slowly and completely digested and possesses a controlling effect on the blood glucose level. In contrast, RS is not digested in the small intestine by endogenous enzymes consequently pass to large intestine where it functions physiologically similar to dietary fibres as it increases faecal bulk, reduces colonic pH, lowers serum cholesterol and triglycerides levels (Fuentes-Zaragoza et al. 2010), and reduces postprandial glycemic responses. Similar to dietary fibres, RS also functions as prebiotics and promotes the growth of probiotics in human gut. However, the fermentation of RS produces higher amount of butyrate as compared to other indigestible carbohydrates.

The RS content of different pulses (beans, chickpeas, lentils, and peas) ranged from 3.95 to 5.09 % against 1.42–2.85 %, respectively for cereals like wheat, rice and barley (Yadav et al. 2010a). The higher RS for pulses is attributed to higher amylose content (30–60 %), absence of pores on the granule surface, C-type crystallinity, strong interactions between amylose chains and lesser tendency to completely lose crystalline- and granular-structure during cooking (Hoover et al. 2010; Singh 2011). Although amylose is a linear polymer of glucose, it is generally digested at slower rate than highly branched amylopectin owing to lesser relative surface area per molecule (Shevkani et al. 2016). In addition, high amylose content of pulse starches results in increased retrogradation, making these more resistant towards amylolysis by the digestive enzymes (Singh 2011). Additionally, the non-starch carbohydrates present in pulse seeds further account for the lower digestibility of pulse starches. As SDF could increase viscosity of the system, these decrease transit time, reducing the time available for starch digestion in the small intestine. The digestibility of whole pulses (beans, lentils, peas and chickpeas) starch after cooking depended on the integrity of the cell walls which prevented degradation of the starches by digestive enzymes as these remained partially crystalline during cooking where the cell walls were not disrupted and the pulses (navy and pinto beans) with more viscous SDF had higher degree of crystallinity in the cell walls than other pulses. Moreover, the protein-starch interactions could further contribute to lesser digestibility of pulse starches (Rebello et al. 2014). Cooking generally reduces RS content; however the extent of this reduction varies with cooking methods. Yadav et al. (2010b) reported lower content of RS in pressure cooked pulses as compared to boiled counterparts attributing to more uniform and complete gelatinization.

Oligosaccharides

Pulses are known to contain the highest contents of some of the oligosaccharides among all the crops. Total oligosaccharides in different pulses, such as lentils, chickpeas and peas were observed to range between 70.7 mg/g DW in yellow peas and 144.9 mg/g DW in chickpeas (Han and Baik 2006). Sucrose, stachyose and verbascose were predominant oligosaccharides in beans. However, major pulse oligosaccharides are α-galactosides which are characterized by the presence of $\alpha\,(1 \rightarrow 6)$ links between the galactose moieties. These are the second most abundant soluble carbohydrates in the plant kingdom after sucrose. Raffinose (trisaccharide), stachyose (tetrasaccharide) and verbascose (pentasaccharide) are predominant α-galactosides present in pulses. Moussou et al. (2016) reported that lentils have the lowest content of raffinose family with 37.5 mg/g DW compared to faba beans (52 mg/g DW), beans (60.9 mg/g DW) and peas (66.3 mg/g DW). They also reported that cotyledons had higher content of these oligosaccharides than seed coats. Other group of α-galactosides in pulses is galactosyl cyclitols, the most common being a trisaccharide ciceritol (Han and Baik 2006). The α-galactosides are not absorbed or hydrolysed by the human digestive system hence fermented by colonic bacteria, resulting in production of flatulent gases responsible for bloating and abdominal discomfort. However, these help in normalizing bowel function, increasing *lactobacilli* and *bifidobacteria* and decreasing *enterobacteria* in the colon, and reducing the levels of potentially carcinogenic N-nitroso compounds in the gut (Van Loo 1998). Raffinose and stachyose were reported to have health beneficial physiological effects similar to those of dietary fibres (Berrios et al. 2010).

Antinutritional factors in pulses and methods of their elimination

Most of the bioactive substances present in pulses have been classified as antinutritional factors or food toxicants (Champ 2002). These include polyphenols, alkaloids, enzyme inhibitors, lectins, phytates and oxalates. Consumption of these substances over a long period of time might have adverse effects. However, in recent years, it has been suggested that they also have human health benefits (such as lowering blood sugar level). Trypsin and chymotrypsin inhibitors are the main enzyme inhibitors present in pulses. They deplete the sulphur-containing amino acids in pulses and can be inactivated by hydrothermic treatments, preparation of protein isolates, ultrafiltration and wet fractionation (Champ 2002). Lectins are sugar-binding proteins that are able to bind and agglutinate red blood cells. They can be eliminated by heat processing (except at a low temperature or with slow cooking). Phytic acid and oxalates are other antinutritional factors present in pulses, that chelate multivalent metal ions (especially Fe, Ca and Zn). Their content can be reduced by germination or by processing (Vidal-Valverde et al. 2001). Alkaloids (nitrogenous organic compounds) and saponins (glycosides that mainly cause foaming) are other class of antinutritional factors present in pulses. Their content can be decreased by processing of pulse seeds. The astringency caused by tannins can be lowered by dehulling the seeds.

Antioxidant activity

Numerous studies have suggested that oxidative stress is involved in health problems such as diabetes, obesity, neural disorders, cancer and cardiovascular diseases. Polyphenols are the primary antioxidants that are based upon the donation of hydrogen atoms to the free radicals (Singh et al. 2016a). They delay or prevent oxidation of lipids, proteins and DNA by reactive oxygen species that is produced in cells during oxidation (Amarowicz et al. 2010). Information regarding antioxidant activity of bioactive compounds present in pulses helps in understanding the role of pulses in human diet to reduce the incidence of chronic diseases. Pulses exerted high antioxidant capacity as determined by DPPH, ORAC and FRAP assays (Xu and Chang 2009). López-Amorós et al. (2006) reported that peas and beans undergo a significant increase in antioxidant activity after germination due to changes in their phenolic composition. Similarly, Moussou et al. (2016) reported an increase in antioxidant activities of different pulse flours with toasting. Amarowicz and Pegg (2008) reviewed antioxidant activity and radical scavenging capacity of pulses. They correlated polyphenols of pulses with antioxidant activity and reduced incidence of chronic diseases. Lentils, chickpeas and kidney bean have shown high antioxidant potential in many studies. Amarowicz et al. (2010) investigated the antioxidant and antiradical activities of green lentil seed extract and its isolated low-molecular-weight phenolics and tannin fractions. Phenolic compounds and its fractions have demonstrated antioxidant and antiradical activities.

Antioxidant activity of pulses is related to concentration of polyphenols. Wang et al. (2016) evaluated antioxidant activities of some selected beans from China. They reported positive correlations between total antioxidant activities and TPC. Moreover, they reported that black bean, spring bay bean and pearl bean showed the strongest antioxidant activities among the analyzed bean varieties. Raw lentils have shown high values of the antioxidant activity (66.9 μmol trolox/g DW) as compared to common chickpeas and peas due to high content of phenolic compounds (Aguilera et al. 2011). Gallic acid is a potent antioxidant present in lentils and it accounts for 95 % of total hydroxybenzoic acids in black lentils. Flavonoids are the main components among phenolics that contributed towards antioxidant potential of pulses. Flavonoids (cyanidin 3-O-β-D-glucoside, pelargonidin 3-O-β-D-glucoside, delphinidin 3-O-β-D-glucoside) present in beans with red and black seed coat have shown strong antioxidative activity (Tsuda et al. 1994). Seed coats of pulses are rich source of flavonoids. Differences have been observed in the antioxidant capacity of seed coat and cotyledon of lentils and dark peas. The seed coats have presented higher antioxidant activity than the cotyledons in lentils and peas and it is related to high flavonoid content (Dueñas et al. 2006).

Pulses with coloured coats have more content of flavonoids and possess strong antioxidant activities. Natural polyphenols in foods are free radical terminators and quench singlet oxygen (Singh et al. 2016b). Cardador-Martínez et al. (2002) demonstrated that red, brown and black beans possess high antioxidative activity as compared to white beans. Many studies have reported that pulses with a dark seed coat show high antioxidant potential owing to large amounts of phenolic compounds such as proanthocyanidins. Madhujith et al. (2004) demonstrated that coloured beans (red, brown and black) possess high antioxidative activity as compared to white beans due to the presence of condensed tannins. The antioxidant activity of lentil cultivars having different seed coat colours was determined with respect to their total phenolic, flavonoid, and condensed tannin (proanthocyanidin) contents (Alshikh et al. 2015). The flavonoid compounds such as anthocyanins, quercetin glycosides and condensed tannins present in seed coat of beans have higher antioxidant activity than simple phenolics (Beninger and Hosfield 2003). Antioxidant potential of bioactive compounds present in legumes have role in controlling chronic diseases like cancer, ageing and diabetes.

Among different pulses studied by Zhao et al. (2014), lentils have shown the high antioxidant capacity (721 U [unit of total antioxidant activity]/g), DPPH assay (38.5 %)

and reducing power, while baby lima bean and navy bean showed the lowest values. Chickpea (648 U/g), small red kidney bean (622 U/g) and black kidney bean (602 U/g) are also good in antioxidant activity. Chaieb et al. (2011) determined antioxidant activities of thirteen faba bean genotypes grown in Tunisia. They reported that faba beans were a good source of natural antioxidants independently to their genotype and a significant correlation among the phenolic content and the DPPH scavenging capacity was found. Antioxidant activities of commonly consumed pulses have been reported by many research groups (López-Amorós et al. 2006; Xu and Chang 2009; Amarowicz and Pegg 2008; Han and Baik 2006; Chaieb et al. 2011; Fratianni et al. 2014; Alshikh et al. 2015; Zhang et al. 2015). The results of studies have indicated that pulses can be used as source of natural antioxidants. Some studies have shown that processing and cooking may reduce the antioxidant activity of pulses. Xu and Chang (2009) determined the effect of boiling as well as steaming under high pressure on phenolic content and antioxidant activities of black beans and pinto beans. They reported that in comparison with the original raw beans, both boiling and steaming caused a significant reduction in the TPC, condensed tannin content, total flavonoid content and antioxidant activities (as determined by DPPH, ORAC and FRAP assays).

Health benefits

Pulses contain significant amount of bioactive compounds with health promoting activities which make them useful for development of functional foods that could be included in the daily human diet. The health benefits of bioactive constituents present in pulses is given in Table 2. The use of pulses in formulation of new food products with beneficial health effects and wellbeing has gained the attention of food industries and consumers due to their nutritional profile and bioactive constituents (Aguilera et al. 2011). Pulses consumed as whole grains by simple cooking deliver more nutrition and health benefits than those taken as components in processed foods. Pulses are known as low GI foods. Pulses have several qualities to improve GI such as low release of carbohydrates and high content of dietary fibre. Dilawari et al. (1987) studied role of pulses on blood sugar level in diabetes mellitus and suggested that intake of pulses can offers benefits for blood glucose control in individuals diabetic. Venn and Mann (2004) reviewed the role of pulses in prevention and management of diabetes and provided strong evidences that consuming whole grain foods like pulses are beneficial in diabetes. Many studies have suggested that pulses offer important protective effects on risk for cardiovascular disease (Anderson and Major 2002). Regular consumption of pulses reduces the risk of cardiac problems due to their favourable affects on blood pressure, glycaemia, diabetes and risk for obesity. Bazzano et al. (2001) found a strong inverse relationship between intake of pulses and risk of heart problems. The cholesterol lowering effect of pulses is mainly due to the isoflavones, phytosterols and non-digestible carbohydrates present in them. Intake of pulses decreases serum cholesterol or LDL–cholesterol by 7 % and serum triacylglycerols by more than 10 % (Anderson and Major 2002). Pulses like beans and lentils are major source of dietary flavonols and they are used in preparing flavonol-rich foods. Dietary intake of flavonols functions as anti-oxidant, pro-oxidant or anti-estrogenic to inhibit breast carcinogenesis. Adebamowo et al. (2005) reported that the lower incidence of breast cancer was related to high intake of beans and lentils. Regular intake of pulses may be an important part of dietary interventions to reduce the risk of cancer.

Pulses contribute towards dietary source of natural antioxidants as they contains significant amount of phenolics and flavonoids (Xu and Chang 2009). Diet rich in pulses may be useful in prevention or treatment of health problems linked with free radical production. Studies have correlated health benefits of consuming pulses with phenolic content of the pulses. Polyphenols are known for their protective effects on oxidative stress-induced diseases and various physiological activities of the body (Aguilera et al. 2011). These compounds have role in promotion of health and prevention of many diseases. Phenolic compounds play role in specific biological functions by modulating the activity of enzymes and cell receptors. In human diet, polyphenols have role in prevention of cancer, cardiovascular and neurodegenerative diseases associated with oxidative stress (Manach et al. 2004). Siah et al. (2012) reported that crude phenolic extracts from raw as well as roasted faba beans had potential health benefit properties such as potent antioxidant activities (based on in vitro and in vivo assays) and chemo-preventative effects. The occurrence of bioactive phenolic compounds and their antioxidant activity/radical-scavenging capacity make pulses a very useful food for daily inclusion in the human diet (Zhao et al. 2014). Zhang et al. (2015) reported that polyphenols present in lentils not only contributed to the antioxidant activities, but they also inhibited glucosidase and lipase (enzymes which are associated with glucose and lipid digestion), contributing to controlling obesity and blood glucose levels in humans. Moreover, polyphenols also function as anti-allergic, antimicrobial, anticancer and anti-inflammatory agents (Daglia 2012). Pea, faba bean and lentil are good dietary source of polymeric flavonoids (Jin et al. 2012). The polymeric flavonoids have health beneficial effects like antioxidant, anti-diabetic, anti-

Table 2 Health benefits of pulses

Pulses	Health benefits	Bioactive constituents with beneficial effect	References
Common bean	Hypolipidemic properties	Phytosterols, Dietary fibres and Resistant starch	Ramírez-Jiménez et al. (2015)
Dried beans	Reduces low-density lipoprotein cholesterol, reduces risk of ischemic heart disease and diabetes	Resistant starch, polyphenols, dietary fibre etc	Rocha-Guzmán et al. (2007)
Beans and Peas	Reduces risk of cardiovascular diseases Decreases cholesterol level	Dietary fibres and proteins	Bazzano et al. (2001)
Common beans	Anti-carcinogenic	Polyphenols and dietary fibres	Campos-Vega et al. (2013)
Beans and lentils	Reduces risk of breast cancer	Polyphenols	Adebamowo et al. (2005)
Chickpea and kidney bean	Lowers blood sugar level	Dietary fibre and carbohydrates	Dilawari et al. (1987)
Common beans	Chemopreventive effect on colon cancer	Polysaccharides	Fuentes-Zaragoza et al. (2010)
Kidney bean	Improves blood lipid profile and enhances fat excretion in overweight and obese subjects	Dietary fibres	Bartnikowska (2009)
Pinto bean	Improve lipid profiles associated with cardiovascular disease	Dietary fibre and resistant starch	Berrios et al. (2010)
Beans	Prevention of colon cancer	Polyphenols, Dietary fibres, Oligosaccharides etc	Vergara-Castañeda et al. (2012)
Pulses	Reduces the risks of obesity	–	Rebello et al. (2014)
Beans	Decreases absorption of fat	Dietary fibres, resistant starch	
Dry beans, peas, chickpeas, and lentils	Helps in weight management	Dietary fibres, resistant starch, Polyphenols, oligosaccharides etc	Rebello et al. (2014)
Pulses	Increases satiety, beneficial in diabetes and heart problems	–	Bazzano et al. (2001)
Faba beans	Anticancer and antioxidant activities	Polyphenols	Siah et al. (2012)
Pinto beans	Reducing risk for cardiovascular disease	Dietary fibre, resistant starch	Wang and Toews (2011)
Navy beans	Decreases cholesterol level		
Pulses	Hypocholesterolemic effect	Phytosterols	Bartnikowska (2009)
Pulses	Prevention of cardiovascular disease	Dietary fibres, isoflavones, phytosterols, oligosaccharides etc	Anderson and Major (2002)
Beans	Anti-mutagenic effect	Polyphenols	Daglia (2012)
Pulses	Prevent colon, breast and other cancers	Resistant starch, oligosaccharides, Isoflavones, phytosterols etc	Dueñas (2016)
Pulses	Prevention and management of obesity and related disorders	Dietary fibres, resistant starch, oligosaccharides etc	Rebello et al. (2014)

carcinogenic, and anti-inflammatory activities. They also contribute in promoting vascular health and improving serum lipoproteins.

Phytosterols are also known for many health promoting activities. Phytosterols reduces cholesterol levels by inhibiting its absorption in the intestinal lumen through the inhibition of cholesterol micellar solubility (Chávez-Santoscoy et al. 2014). Phytosterols intake of around 3 g per day significantly decreases the total cholesterol level by 10–15 % and is very effective in reducing serum LDL cholesterol levels (Nyström et al. 2012). Dietary sources of phytosterols usually come from pulses, corn and some plant oils. Plant sterols may attenuate the inflammatory activity of immune cells and prevent immunological diseases (Bouic 2001). They are known for anti-cancer, anti-inflammatory, anti-oxidative and immune modulatory activities (Bartnikowska 2009). Phytosterols affect many metabolic processes. They play an important role in the hypocholesterolaemic effects of pulses. Hyperlipidemia is involved in the development of several chronic diseases. Phytosterols have important role in reducing the risk of cardiovascular diseases by lowering absorption of lipids at intestinal level in people consuming pulses as food (Kushi et al. 1999; Chávez-Santoscoy et al. 2014). Phytosterols, dietary fibre and resistant starch present in pulses have hypolipidemic benefits (Ramírez-Jiménez et al. 2015).

The SCFA produced by bean fibre fermentation were associated with the regulation of appetite and satiety, acetic and propionic acids influenced serum lipid profiles (Ramírez-Jiménez et al. 2015). SCFA, in particular butyrates, exhibited potent anti-tumour and anti-inflammatory activities while propionate decreased serum cholesterol levels, inhibited fatty acid synthesis and induced satiety (Lanza et al. 2006). The indigestible fractions from black bean and lentil were observed to be the best substrate for the production of SCFA (particularly butyric acid) by Hernández-Salazar et al. (2010). However, McBurney and Thompson (1987) showed that the fermentation of whole black bean resulted in the production of higher levels of acetic acid than propionic and butyric acids.

Dietary fibres present in pulses have beneficial effects in many human health problems. The main properties relating to health benefits of SDF are viscosity, water holding capacity (WHC), organic compound entrapment, and fermentability. SDF are more easily fermented in the large intestine than IDF. Some SDF increase viscosity of bolus resulting in stomach distension, delayed gastric emptying rate, slower intestinal transition and reduced absorption rate of nutrients, resulting in increased satiety and controlled postprandial glucose and lipids levels (Rebello et al. 2014), making them a good choice for people with type-2 diabetes, obesity and cardiovascular diseases. Furthermore, the SDF had the ability to bind bile acids, leading to reduced absorption of dietary cholesterol (Kahlon et al. 2005). Therefore, the consumption of 5–10 g soluble fibre/day was reported to reduce low-density lipoprotein (LDL) cholesterol by approximately 5 % (Panel 2002). IDF are fermented slowly and do not form viscous gels (contrary to that of SDF). However, IDF act as bulking agent in the intestine, increasing both the size and weight of food remnants (due to their high water binding capacity and resistance to degradation by bacteria), resulting in laxation. IDF act primarily in the large intestine where these increases faecal bulk, dilutes colonic contents and decreases mouth-to-anus transit time. Therefore, pulses with high content of IDF could also be helpful in regulating bowel movements which were associated with the reduced risk of colon cancers (Costa et al. 2006). This review suggested that pulses are carriers of several bioactive constituents of potential biological importance which contributes to human health and wellbeing.

Conclusion and future prospective

People nowadays face many health problems, which can be prevented or treated by increasing consumption of nutritional foods that rich in beneficial bioactive constituents. Pulses are important part of human diet in many countries of the world. Pulses are low-fat, dry seeds of legumes such as beans, peas, chickpeas, and lentils. Pulses not only provide significant amount of proteins, carbohydrates and micronutrients but are also rich in bioactive constituents like polyphenols, phytosterols, resistant starch, oligosaccharides and dietary fibre that are beneficial for managing and preventing chronic diseases. Pulses have a low glycemic index and are rich source of dietary fibre and antioxidants. Including pulses in our diet can contribute to prevent or cure diabetes, heart problems, obesity and certain types of cancers. The contribution of phytosterols, resistant starch and dietary fibres to hypocholesterolaemic effect of pulses has a significant importance. Regular intake of pulses can improve heart health and lowers blood cholesterol. Studies have provided evidences that many chronic diseases can be prevented by including pulses in our regular diet as therapeutic functional foods. Furthermore, epidemiological studies and clinical trials should be carried for detail information about role of bioactive compounds present pulses in our health. Effect of processing and cooking methods on nature and content of bioactive constituents in pulses is an area which requires more investigations. Many possibilities currently exist in this area for further studies.

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