REVIEW

Review of the health benefits of Faba bean (*Vicia faba* L.) polyphenols

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Summary

The dietary consumption of legumes is associated with a lower incidence of chronic degenerative diseases. Among legumes, a growing interest is devoted to Faba bean (*Vicia faba* L.), also known as broad bean. Faba bean nutritional properties have been previously studied and several polyphenols (mainly flavonoids) have been evaluated in broad bean extracts. In our study, the literature on polyphenol content in different varieties of Faba bean and on factors that modulate their levels was reviewed. Also, data on bioaccessibility and bioavailability of the main polyphenols contained in Faba bean were reviewed. The molecular mechanisms, antioxidant, anti-inflammatory and anti-diabetic properties, by which Faba bean polyphenols could be involved in the protection against the development of human diseases are described.

Keywords

legumes; Faba bean; phytochemicals; nutrition; functional foods; polyphenols, flavonoids

Legumes have beneficial health implications related to their nutritional properties [1–5]. They are an important source of macronutrients, containing almost twice the amount of proteins compared to cereal grains. In addition, they are an excellent source of dietary fibre, choline, lecithin, folate and secondary metabolites such as polyphenols, which exert many biological properties and have a key role in human health [1–5]. Legumes are also a good source of different mineral elements such as calcium, iron and zinc, however, their bioavailability is low [6]. The low bioavailability is related to phytochemicals such as phytic acid and polyphenols [6–8]. The problem deserves attention among populations that derive minerals primarily from raw plant-based diets. However, recent studies demonstrated that different polyphenols exert opposite effects on iron bioavailability [7]. Moreover, various processing methods such as roasting, soaking, germination or fermentation decrease the levels of anti-nutritional factors and significantly improve in vitro availability of iron and zinc [9, 10].

Among legumes, a growing interest is devoted to Faba bean (*Vicia faba* L.) for its positive nutritional properties [10–14]. Faba bean, commonly named broad bean, horse bean and field bean, belongs to the family of *Fabaceae*. It is one of the major winter-sown legume crops. It has an important place in the traditional diets of the Mediterranean, Indian, Chinese, English, Middle Eastern, African and South American, and has considerable importance as a low-cost food rich in proteins and carbohydrates [10–14]. Broad beans are harvested at vegetative stage when the pods and seeds are fresh and green, and used as a vegetable. Alternatively, they can be harvested at maturity stage after the pods and beans dry out. *V. faba* beans composition (carbohydrates, fibres, proteins, vitamins and minerals) and non-protein anti-nutritional factors (saponins, phytic acid alkaloids and tannins) was previously studied [13–15]. Interestingly, in con-

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trast to cereals, Faba bean was found to contain high levels of lysine and arginine, which may complement the low levels of those in cereals.

For the first time, in 1913, Guggenheim identified L-3,4-dihydroxyphenylalanine (L-DOPA) [16], the precursor of dopamine, in the seedlings, pods and beans of *V. faba*. More recently, a potential role of *V. faba* intake in management of Parkinson disease has been suggested [17, 18]. However, more research is necessary to determine the role of Faba beans in Parkinson's disease.

Broad beans also contain alkaloids that should be taken into account for certain people suffering from favism, an inherited disease in which the enzyme glucose-6-phosphate dehydrogenase (G6PD) is deficient [19]. Vicine and convicine are natural pyrimidine glucosides found in the Faba bean plant and are likely to be involved in plant defense mechanisms against pathogens. The aglycone derivatives, divicine and isouramil, are responsible for favism occurrence [19]. Some common treatments induce modifications of alkaloids content and L-DOPA in Faba beans [20, 21].

The role of Faba bean as a source of protein in human diet and the role of non-nutritional factors (saponins, lectins, tannins, phytic acid) which modulate nutrient bioavailability was recently reviewed [15]. Recent papers suggest that Faba bean and derivatives could represent a suitable food in treatment of diabetics, in hypertension and may help to prevent cardiovascular disease [22]. Among bioactive molecules involved in the molecular mechanisms, which contribute to prevention of chronic-degenerative disease, a key role is exerted by plant polyphenols [1, 23, 24]. This is the first review on Faba bean nutritional properties with particular attention to its polyphenols and their potential protective effect against the development of human diseases. Therefore, the literature on polyphenol content in different varieties of Faba bean and on factors that modulate their levels was reviewed. Also, data on polyphenol bioaccessibility and bioavailability, as well as on molecular mechanisms by which polyphenols could be involved in the protection against the development of human diseases were reviewed.

Faba bean composition

Macronutrients and dietary fibres

The protein content of Faba bean seeds ranges from 200 $g \cdot kg^{-1}$ to 410 $g \cdot kg^{-1}$, which depends on the variety. Faba bean seeds contain 510 $g \cdot kg^{-1}$ to 680 $g \cdot kg^{-1}$ of carbohydrates in total, the major proportion of which is constituted by starch (410–530 $g \cdot kg^{-1}$). Lipids are contained at 12–40 $g \cdot kg^{-1}$. Dietary fibre ranges between 150 $g \cdot kg^{-1}$ and 300 $g \cdot kg^{-1}$, which depends on the seed variety, hemicellulose being the major component [10–13].

Micronutrients

Vitamin C

The effect of processing on vitamin C has been studied in different varieties by Kmiecik et al [25]. The vitamin C content decreased with increasing degree of seed ripeness in the range from 25 % to 40 %. Blanching decreased the vitamin C content by 14–43 %. Freezing of blanched seeds and a 6-month storage of frozen goods decreased the vitamin content by approximately 24–56%. Frozen whole seeds contained 93–138 $mg \cdot kg^{-1}$ of vitamin C after cooking (compared with fresh seeds, the losses reached 56–73 %) and appertized canned seeds contained 82–117 $mg \cdot kg^{-1}$ (compared with fresh seeds, the losses reached 63–73 %).

Folate

Faba beans are also a source of folate. Industrial food processing (e.g., canning or freezing), germination, cultivar, and maturity stage modulate the folate content [26]. The folate content in four cultivars of green Faba beans ranged from 1.1–1.3 $mg \cdot kg^{-1}$ fresh weight, which was four- to six fold higher than in dried seeds [26]. Industrial canning of dried seeds resulted in significant folate losses of approximately 20 %, while industrial freezing had no effect [26]. Germination of Faba beans increased the folate content by > 40 % [26].

Carotenoids and tocopherols

Grain legumes are included among the dietary sources of carotenoids (including provitamin A) and tocopherols (vitamin E), which play pivotal roles in the prevention of inflammatory processes, as well as coronary, neuromuscular and visual disorders. Fernández-Marín et al. [27] demonstrated that domestication of grain legumes was accompanied with a reduction in carotenoids contents.

Polyphenols

Polyphenol content

Among phytochemicals, phenolic compounds are gaining an increasing interest for their health-promoting properties [23, 24, 28]. They are widely distributed in fruits, vegetables and beverages (tea, coffee, wine) [23, 24, 28, 29]. All polyphenols contain one or more aromatic rings with one or more hydroxyl group as substituents. Depending on the number of these phenol rings and on the structural elements bound to them, polyphenols are classified into different groups [28]. Polyphenols in Faba beans are located in several parts of the plant (e.g. leaves, roots and seeds) [30, 31]. Faba bean cotyledons have higher contents than their respective hulls or whole seeds [32]. Previous studies provided data mainly the levels of total polyphenols, total flavonoids and total tannins in seeds of different Faba bean varieties [31–35]. As summarized in Tab. 1, a large variability of the levels of total polyphenols in seeds of different varieties has been observed. The comparison of polyphenol levels of extracts obtained using different solvents demonstrated that ethanol extracts contained higher levels of polyphenols compared with extracts obtained using acetone [32].

Recently, Abu-Reidah et al. [36] identified a total of 104 phenolics, mainly flavonoids in Faba beans. The main classes are shown in Tab. 2. Flavonoid compounds found in Faba beans, include flavanol monomers (such as gallocatechin, epigallocatechin and catechin), proanthocyanidins (prodelphynidins and procyanidins), flavonols (glycosylated derivates of myricetin, quercetin and kaempferol), flavanonols, isoflavones (genistein and daidzein) and flavanones. Moreover, other phenolic compounds were found in Faba beans, including phenolic acids (caffeic acid, ferulic acid, *p*-coumaric acid and synaptic acid) [36–38]. The contents of individual phenolic compounds in Faba bean samples are shown in Tab. 3.

In addition to genetic factors, total phenolic content in seeds is modulated by other factors such as growing stage (vegetative, reproductive and mature). Immature Faba bean fractions have significantly higher phytochemical contents and display a better antioxidant activity than those of mature ones [34, 39].

Effect of processing on polyphenol levels

Faba beans can be consumed fresh or after cooking. Their polyphenol profiles are affected

Tab. 1. Levels of total polyphenols in seeds of different Faba bean varieties.

Variety	Country	Total polyphenols [mg·kg^{-1}]	Extraction
Subspecies *Vicia major*	Algeria [32]	9 530	A
		30 930	B
Subspecies *Vicia minor*		4 490	A
		42 440	B
TF(Ic*As)*483/13	Australia [33]	2 800	A
Doza		8 600	A
Nura		10 900	A
Icarus		10 800	A
Rossa		11 200	A
5%LSD		500	A
Super Aguadulce Agrical	Chile [31]	1 060	C
Super Aguadulce Anasac		1 180	C
Portuguesa INIA		1 140	C
Luz de Otono		820	C
Reina Mora		1 320	C
Alargŕ		1 340	C
Retaca		940	C
Verde Bonita		1 010	C
HBP/SO A/2005		1 100	C
HBP/SO B/2005		1 110	C
G1	Tunisia [34]	21 480	B
G3		28 650	B
G4	Tunisia [34]	35 170	B
G5		27 840	B
G6		25 630	B
G7		30 200	B
G8		24 460	B
G9		16 980	B
G10		38 100	B
G11		45 590	B
G12		43 930	B
G13		41 050	B
G14		67 470	B
AO155	Canada [35]	30 940 *	B
AZ10		34 990 *	B
Disco		5 590 *	B
Divine		6 180 *	B
Fatima		31 770 *	B
FB25-56		40 630 *	B
Florent		30 920 *	B
Imposa		37 780 *	B
Melodie		6 170 *	B
NPZ4-7540		35 330 *	B
Snowbird		37 760 *	B
SSNS-1		36 740 *	B
Taboar		36 060 *	B

Data are presented as milligrams of gallic acid equivalent per kilogram of Faba bean seeds on dry matter basis (* – data are presented as milligrams of catechin equivalent per kilogram of Faba bean seeds on dry matter basis).
Solvent used to prepare extracts: A – acetone/water, B – ethanol, C – methanol/water.

Tab. 2. Phenolic compounds characterized in *Vicia faba* L. seeds extract [36].

Class	Compounds
Flavanol monomers	gallocatechin, (epi)gallocatechin, (epi)gallocatechin hexose I, (epi)gallocatechin dihexoside, catechin, epicatechin, (epi)catechin di-*C*-glucoside, (epi)afzelechin, 4'- or 5'-*O*-methyl-(epi)catechin I
Prodelphynidins	(epi)gallocatechin-(epi)gallocatechin I, (epi)gallocatechin-(epi)gallocatechin II, (epi)gallocatechin-(epi) gallocatechin III, (epi)gallocatechin-(epi)gallocatechin IV, (epi)gallocatechin-(epi)catechin I, (epi)gallo-catechin-(epi)catechin II, (epi)gallocatechin-(epi)catechin III, (epi)gallocatechin-(epi)gallocatechin V, (epi)catechin-(epi)gallocatechin II, (epi)gallocatechin-(epi)gallocatechin VI, (epi)catechin-(epi)gallocate-chin III, (epi)catechin-(epi)gallocatechin IV, (epi)gallocatechin-(epi)gallocatechin VII, (epi)gallocatechin-(epi)gallocatechin VII, (epi)catechin-(epi)gallocatechin VI
Procyanidin	(epi)catechin-(epi)catechin(procyanidin B I), (epi)catechin-(epi)catechin II (procyanidin B II), (epi) catechin-(epi)catechin II (procyanidin B III), (epi)catechin-(epi)catechin II (procyanidin B IV)
Phenolic acid	salicylic acid *O*-glucoside, protocatechuic acid hexoside, 3'-*O*-methyl(3',4'-dihydroxybenzyl tartaric acid)(3'-*O*-methylfukiic acid), hydroxyeucomic acid, hydroxybenzyl-malic acid (eucomic acid)
Flavanone	naringenin 7-glucoside (prunin), dihydrochrysin (pinocembrin)
Flavone	isoschaftoside, apigenin 8-or-6-*C*-glucoside (vitexin or isovitexin)
Flavonol	myricetin hexose I, quercetin hexose deoxyexose II, kaempferol3-*O*-α-L-arabinopyranosyl-7-*O*-α-L-rhamnopyranoside, myricetin hexose III
Stilbene	resveratrol, resveratrol 3-*O*-ß-D-glucoside
Dihydrochalcone	phloretin 3',5'-di-*C*-glucoside
Isoflavone	genistein, formonetin, daidzein

by processing such as soaking, sprouting, freezing, boiling, pressure cooking and steaming [33, 40–42]. Roasting Faba beans for 120 min decreased the total phenolic, flavonoid and proanthocyanidin contents by 42 %, 42 % and 30 %, respectively, but also caused generation of new phenolic compounds [40]. Soaking, boiling and autoclaving caused loss in phenolic compounds and antioxidant activities due to leaching of compounds into the soaking and cooking medium.

Tab. 3. Contents of individual polyphenols in Vicia faba seeds.

Polyphenols	Polyphenol level [$mg\cdot kg^{-1}$]	Reference
(+)-Catechin	84–978	[31]
(–)-Epicatechin	140–700	[31]
Total flavonols + flavones	100–370	[31]
Proanthocianidins	542–3363	[31]
Total phenolic acids	156 ± 13.3	[37]
Caffeic acid	7.8 ± 0.3	[37]
p-coumaric acid	16.8 ± 0.7	[37]
Sinapic acid	25.8 ± 2.3	[37]
Ferulic acid	105.6 ± 15.8	[37]
Total isoflavone	24.9	[38]
Daidzein	5	[38]
Genistein	19.9	[38]

Boiling was shown to be a better method than autoclaving in retaining phenolic compounds, and the authors suggested that home-cooked Faba beans may contain higher levels of phenolic compounds than industrially processed Faba beans [33]. Even sprouting, a process involving germination and drying of legume seeds, was found to decrease total polyphenol content and was associated with improvements in the nutritive value in sprouted seeds [10]. A significant decrease in tannin content was also observed in irradiated Faba beans [43]. Due to the aforementioned inhibitory effect of tannins and other anti-nutritional factors on mineral bioavailability, all the treatments significantly improved in vitro availability of minerals [9].

Bioactive roles of Faba bean polyphenols

The biological activities of Faba bean polyphenols was recently evaluated using different experimental models. Faba bean polyphenols behave as antioxidants and modulate other cell functions with an interesting potential for various fields of medicine.

Antioxidant properties

Antioxidant activity and scavenging properties

A wide variety of antioxidants, such as vitamins C, vitamin E, carotenoids, terpenoids and polyphenols, contribute to the antioxidant capacity of plant foods [28]. The antioxidant capacity of extracts from Faba bean was widely investigated using different methodological approaches such as ferric-reducing antioxidant power assay (FRAP), oxygen radical absorbance capacity (ORAC), determination of the scavenging effect on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals and by evaluation of total equivalent antioxidant capacity (TEAC).

The antioxidant properties of extracts of Faba beans are related to total phenolics and total flavonoids contents. Differences were observed for different genotypes collected during three different growing stages (vegetative, reproductive and mature) [39]. The results showed also different antioxidant properties for the same genotype when considering the different parts of the plant. Higher contents of total phenolics and flavonoids were found during vegetative and reproductive stages, which also showed the highest antioxidant activity (FRAP values ≥1.157 mol·kg^{-1}) and the highest DPPH radical-scavenging capacity. Using an ORAC assay, it was reported that the antioxidant capacity ranged from 109 mmol·kg^{-1} to 149 mmol·kg^{-1}, expressed as Trolox equivalents.

The effects of food processing on DPPH radical-scavenging activity, TEAC, ORAC and FRAP of Faba bean genotypes were studied [33, 40]. A significant loss of phenolic compounds after soaking, boiling, autoclaving and roasting correlated with the decrease of antioxidant capacities [33, 39, 40–42].

Protective effect against free-radical-mediated damage to DNA

Various chemical agents cause DNA single-strand breaks [44]. A protective effect of Faba bean extracts against peroxyl radical-induced DNA strand scission was observed using peroxyl free radicals (ROOH) produced from thermal decomposition of 2,2'-azobis(2-amidinopropane hydrochloride) (AAPH) on Bluescript-SK+ plasmid DNA. A protective effect was exerted also against hydroxyl radical-induced DNA strand scission generated by UV photolysis of hydrogen peroxide (H_2O_2) [45]. $ROO^{\bullet}$ radicals comprise one of the major factors initiating the cascade reactions of lipid peroxidation [46], therefore, it is possible to suggest that Faba bean polyphenols may prevent lipid peroxidation. It was hypothesized that the protective activity of Faba bean extracts against hydroxyl radical-induced DNA damage may be due to their ability to prevent the reaction of hydroxyl radical with hydrogen atoms at C3', C4' and C5' sites of the sugar moiety of DNA [45].

Inhibition of enzyme activities

The enzymes whose activity is inhibited by polyphenols obtained from Faba beans are shown in Tab. 4.

Angiotensin-converting enzyme

Siah et al. [43] demonstrated that polyphenols of three Australian-grown Faba beans genotypes (Nura, Rossa and TF(Ic*As)*483/13 variety) exerted inhibitory effects on angiotensin-converting enzyme (ACE), a key blood pressure regulator, which is responsible for vasoconstriction that leads to an increase in blood pressure [47]. Extracts from Nura variety exhibited the greatest ACE inhibitory activity both in raw and roasted beans, followed by extracts from Rossa variety. Roasting treatment reduced significantly ACE inhibitory activity. The decrease was related to roasting-induced decrease of polyphenol content [43]. Inhi-

Tab. 4. Molecular mechanisms by which Faba bean polyphenols could exert a protective role against the development of human diseases.

Protective role	Molecular mechanism
Protective effect against oxidative stress	Antioxidant effect
	Scavenging properties
	Inhibition of peroxyl radicals–triggered damage to DNA
	Inhibition of the enzyme 15-lipoxigenase
	Inhibition of the enzyme xanthine oxidase
Antihypertensive effect	Inhibition of angiotensin-converting enzyme (ACE)
Chemopreventive effect	Inhibition of topoisomerase I
	Regulation of proliferation and apoptosis
Antidiabetic properties	Inhibition of the enzyme α-glucosidase
	Inhibition of protein glycation (triggered by glucose or methylglyoxal)
	Modulation of production of receptors for advanced glycation end-products in endothelial cells.

bition of ACE activity can potentially prevent the enzyme ACE from elevating blood pressure, reducing the incidence of hypertension.

α-Glucosidase and lipase

Faba bean polyphenols inhibit also the enzymes α-glucosidase and lipase [43], which are important in the digestive tract, being responsible for carbohydrate and lipid digestion. Inhibition of α-glucosidase activity could potentially reduce starch digestion and sugar absorption, contributing to a lower postprandial glycemic response. Therefore, α-glucosidase has been recognized as a therapeutic target for modulation of postprandial hyperglycaemia. The inhibition of lipase activity could reduce fat uptake. Among extracts obtained from both raw and roasted beans, the variety Rossa exhibited the highest α-glucosidase inhibiory activity, followed by Nura variety [43]. Roasting was found to decrease the level of α-glucosidase inhibitory activity of both genotypes. The decrease of inhibition of α-glucosidase in roasted beans was not related to roasting-induced decrease of polyphenol content [43]. Regarding molecular mechanisms involved in the inhibition of the enzymes, formation of proanthocyanidin-enzyme complexes was proposed [43].

Xanthine oxidase

Xanthine oxidase (XO), the enzyme which participates in purine degradation, is the main contributor of free radicals during exercise [48]. It uses molecular oxygen as the electron acceptor, thereby resulting in production of superoxide radical ($O_2^{-\bullet}$) and hydrogen peroxide (H_2O_2) [42]. XO is also involved in pathogenesis of several diseases such as vascular disorders, diabetes, cancer and gout [49]. SPANOU et al. [50] demonstrated that extracts of Faba beans behaved as potent inhibitors of XO. The concentrations of extracted compound mixtures required to give 50% inhibition (IC_{50}) of XO activity ranged from 40 $\mu g \cdot ml^{-1}$ to 135 $\mu g \cdot ml^{-1}$ [50]. The compunds identified as XO inhibitors were flavonoids (mainly quercetin and kaempferol glycosides) and a structure-related inhibitory activity was demonstrated. The most potent inhibitor of XO in Faba bean extracts was kaempferol 3-*O*-(5-*O*-acetyl-β-D-apiofuranosyl)-7-*O*-α-L-rhamnopyranoside [50].

15-Lipoxigenase

Anti-inflammatory activity of ethanol hull extracts from two Faba bean subspecies, *Vicia major* and *Vicia minor*, was evaluated testing the inhibition of the enzyme 15-lipoxigenase (15-LOX) [32]. 15-LOX is involved in the molecular mechanisms of atherosclerosis, participating in oxidative modifications of low-density lipoproteins (LDL) [51] The ethanol hull extracts inhibited 15-LOX in the order *V. minor* > *V. major*. Literature data suggest that the effect could be mediated by flavonoid compounds [32].

Tyrosinase

Recently, it was reported that edible beans have tyrosinase inhibitory activities [52]. It has been shown that broad bean extract exerts a tyrosinase inhibition activity that is significantly correlated with total phenols and antioxidant capacity evaluated using DPPH assay. Acting as a key enzyme for synthesis of melanin pigments, tyrosinase catalyses two distinct reactions in melanin synthesis, namely, hydroxylation of L-tyrosine to L-DOPA and oxidation of L-DOPA to dopaquinone, while from the latter compound, after further series of conversions, melanin is produced [53]. Inhibitors of tyrosinase have been used to treat some dermatological hyperpigmentation illness connected with overproduction of melanin.

Chemopreventive effect, regulation of cell proliferation and apoptosis

Previous studies suggested that polyphenols also modulate cell signaling and could behave as potential anticancer agents [28, 29]. In the past few years, polyphenol antioxidant capacity has been taken into account as one of the outstanding mechanisms of action to inhibit mutagenesis and cancer initiation, by means of their capacity to scavenge reactive oxygen species (ROS), activate antioxidant enzymes, prevent carcinogen-induced DNA adduct formation, enhance DNA repair and reduce overall oxidative DNA injury [28, 29, 54]. Oxidative stress, peroxyl radicals and lipid peroxidation products can independently cause mutations in DNA, which are known to be crucial for the initiation of the carcinogenic process [54]. As aforementioned, Faba bean fractions exhibit a radical-scavenging capacity and protective ability against free radical-induced DNA damage. They exert also an inhibitory role regarding topoisomerase I [43]. Topoisomerase I is one of the enzymes playing a crucial role in replication, transcription, recombination, chromosome condensation and maintenance of genome stability [55]. Because it is an essential enzyme for vital functions of DNA during normal cell growth, inhibitors of its activity are considered to be promising anticancer agents [55].

The ability of Faba bean extracts to inhibit proliferation of different human cancer cell lines (BL13, AGS, Hep G2 and HT-29) was observed by Siah et al. [43]. Faba beans extracts, applied at a concentration range of 0.2–2.0 mg·ml^{-1}, exhibited a dose-dependent suppression of proliferation of all of the tested human cancer cells, while exhibiting a negligible anti-proliferation effect on the non-trasformed human colon CCD-18Co cells. Flow cytometric analyses showed that Faba bean extracts successfully induced apoptosis of HL-60 (acute promyelocytic leukaemia) cells [43].

Modulation of protein glycation and formation of advanced glycation end-products

Advanced glycation end-products (AGE) have a role in the molecular mechanisms of diabetic complications including neuropathy, nephropathy, retinopathy, atherosclerosis and cataracts [56]. Thus, the discovery and investigation of AGE inhibitors would offer a potential therapeutic approach for the prevention of diabetic complications. Yang Yao et al. [37] demonstrated that Faba bean extracts inhibit glycation of bovine serum albumin (BSA) triggered by glucose or methylglyoxal (MGO), and formation of AGE [37]. The authors demonstrated that inhibition of glycation of BSA significantly correlated with total phenols [37].

Modulation of esRAGE production on glucose-treated endothelial cells

Receptors for advanced glycation end-products (RAGE) are members of the immunoglobulin superfamily and multiligand receptors for the late products of non-enzymatic glycation AGE [57]. RAGE is also known to be involved in microvascular complications in diabetes through oxidative stress generation, regulation of atherogenesis, the angiogenic response, and vascular injury [57]. Human vascular cells express an endogenous secretory receptor for advanced glycation end-products called esRAGE. These neutralize AGE action on endothelial cells. Therefore, RAGE antagonists are in clinical development as therapeutics for diabetes complications. Okada et al. [58] showed that methanolic extracts from Faba bean and other plant foods have a modulatory role regarding esRAGE production potential on glucose-treated endothelial cells [58]. It was suggested that polyphenols of methanol extracts, in particular quercetin, could be involved in the bioactive effect. The results could have a physiopathological relevance because the interference with the activation of RAGE was shown to prevent or ameliorate vascular complications in experimental studies [59].

Bioavailability of Faba bean polyphenols in humans

To exert their health effects, dietary polyphenols should be bioavailable. Concentrations and solubility of polyphenols modulate their bioavailability. Moreover, their bioavailability depends on their release from the food matrix, which is referred to as bioaccessibility [60–62]. On oral consumption, the uptake of polyphenols into the body is not complete, and a certain percentage is not absorbed [60–62]. It was suggested that the gastro-intestinal tract may act as an extractor where polyphenols are progressively released from the solid matrix and made available for the absorption or to exert their biological effects in the gastrointestinal tract [60–62]. Prerequisites for polyphenols to have any in vivo systemic effects are that they must be absorbed from the gastrointestinal tract after food consumption and, subsequently, reach sufficiently high plasma concentrations in the systemic circulation to induce biological activity. Several studies evaluated bioaccessibility and bioavailability of legume polyphenols in vitro and in vivo [60–64].

Among flavonoids contained in Faba bean, there are isoflavones. They have structural similarities to estrogens including the ability to bind to estrogen receptors, and they are consequently classified as phytoestrogens. Previous studies showed that genistein and its glycoside genistin, either as pure compounds or from a soy protein isolate extract, are bioavailable. Genistin is partly absorbed in its glycosidic form. Both intestine and liver are involved in deglycosylation and uptake of these glycosylated flavonoids. Human studies showed that also daidzein is bioavailable. Both isoflavones are recovered in urine samples. It was suggested that plasma concentrations of daidzein and genisten may be sufficient to exert some health-protective effects [64].

Faba beans are also a source of proanthocyanidins, also known as condensed tannins. The proanthocyanidins found in food cover a wide range of degree of polymerization (DP). Most of them pass unaltered to the large intestine where they are catabolized by the colonic microflora yielding a diversity of phenolic acids, which are absorbed into the circulatory system and excreted in urine [65, 66]. However, recent studies suggest that only the low-molecular-weight oligomers (DP $<$ 3) are absorbed intact in the gastrointestinal tract [65, 66].

Flavonols are the most ubiquitous flavonoids in foods, with main representatives being myricetin, quercetin and kaempferol [67]. The bioavailability of flavonols, in particular quercetin, has been widely investigated in fruits and vegetables. Literature data indicate that, after ingestion, quercetin glycosides are metabolized, absorbed and circulate in the blood as types of conjugates [68].

Faba beans contain also phenolic acids. Previous studies demonstrated that phenolic acids are bioavailable. When they are in aglycone form, they are generally absorbed in the upper part of the gastro-intestinal tract. Gallic, caffeic, ferulic, coumaric acids but also chlorogenic acid can be absorbed from the stomach [69].

CONCLUSIONS

Plant-based diets and an increase in legume intake exert health benefits. Several studies have shown that the prevention of diabetes, cardiovascular disease and obesity are beneficial health effects attributable to polyphenols found in fruits, vegetables and legumes. Among legumes, Faba beans are a good source of polyphenols. Various factors modulate their levels and composition of Faba beans. A significant correlation between the phenolics content and antioxidant properties has been found. In addition to genetic factors, food processing (soaking, cooking, sprouting) induce compositional changes in Faba bean polyphenols. These modifications improve the nutritional properties of Faba beans because some polyphenols are well known as inhibitors of mineral bioavailability. Faba bean extracts have antioxidant and anti-inflammatory properties. The anti-diabetic properties are supported by the inhibition of α-glucosidase, a key enzyme for carbohydrate digestion, located in the epithelium of the small intestine. α-Glucosidase has been recognized as a therapeutic target for modulation of postprandial hyperglycaemia, which is the earliest metabolic abnormality to occur in type 2 diabetes mellitus. Inhibition of intestinal α-glucosidases delays the digestion and absorption of carbohydrates, thereby contributing to suppression of postprandial hyperglycaemia. Furthermore, Faba bean extracts inhibit protein glycation and es-RAGE production in glucose-treated endothelial cells. Previous studies reported that polyphenols can suppress the formation of AGEs, by preventing glycoxidation and/or by sequestering reactive 1,2 dicarbonyls, such as methylglyoxal, a precursor of AGEs [70]. Other biological properties exerted by Faba bean polyphenols include anti-hypertensive and chemopreventive effects. We suggest that also these biological effects could be exerted by flavonoids, such as catechin and isoflavones, as demonstrated previously [71]. In conclusion, Faba beans represent a useful source of bioactive molecules and their intake contributes to prevention of chronic degenerative diseases.

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