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Phenolic Compounds in Legumes: Composition, Processing and Gut Health

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Abstract

Gut health is fundamental for human well-being and prevents chronic degenerative diseases and is influenced by the interaction between gut microbiota and food components. In recent years, interest in phenolic compounds has increased due to their health benefits such as antioxidant, antidiabetic, antimicrobial, anti-atherosclerotic, anti-inflammatory, anticarcinogenic, cardio- and neuro-protective properties. Legumes are an essential source of phytochemicals, particularly flavonoids and phenolic acids, distributed mainly in the seed coat, and have been reported to exhibit multiple biological effects. Flavonoids present in legumes have been shown to regulate metabolic stability and membrane transport in the intestine, thus improving bioavailability. Seed processing such as cooking allows the release of phenolic compounds, improving polyphenols digestion and absorption at the intestinal level, maintaining their protective capacity in the oxidative process at the cellular level, and modulating the gut microbiota. All these actions improve gut health, avoiding diseases like irritable bowel syndrome, inflammatory bowel disease, obesity, diabetes, colitis, and colorectal cancer. The effect of the consumption of legumes such as chickpea, pea, and bean, as well as the contribution of phenolic compounds to gut health, will be reviewed in this study.

Keywords: Legumes, biological effects, phenolic compounds, seed processing, chronic degenerative diseases, gut microbiota, gut health

1. Introduction

Eating habits are an important factor in the structure, formation, function, and modulation of the gut microbiota, which plays a crucial role in health; environmental factors, antibiotics, and lifestyle also contribute to the dysbiosis of the gut microbiota responsible for gastrointestinal diseases, like colon cancer. Several studies have shown that the gut has a greater impact than food processing and nutrient absorption. Gut health is a function of the gut barrier and gut microbiota essential elements for better health [1–6].

Plants contribute diverse bioactive compounds to the diet [7, 8], including phenolic compounds. Legumes are part of the basic foods with great nutritional relevance due to their content of diverse phenolic compounds that promote health [5, 9]. These compounds are distributed in the whole seed and are mainly responsible for the seed coat color that depends on the composition and concentration [10–14]. The potential health benefits of phenolic compounds in the diet depend on their absorption and metabolism, which in turn are determined by their structure, including their conjugation with other phenols, degree of glycosylation/acylation, molecular size, and solubility [9, 15–17]. During seed processing, phenolic compounds can undergo various changes, altering their antioxidant activity [18, 19].

However, the presence of phenolic compounds and their mechanisms of action in preventing colon cancer or inflammation are probably mediated by the functional composition of the gut microbiota [20–22]. Epidemiological studies have confirmed that regular consumption of legumes has been associated with lower risk due to immunomodulatory effects and prevention of chronic and metabolic diseases, such as cardiovascular diseases, diabetes, cancer, and obesity, in addition to improving gut health [11, 16, 20, 23, 24].

During the absorption of phenolic compounds, like hydroxycinnamic acids (p-coumaric, caffeic, and ferulic) in free and conjugated forms, they are metabolized by the gut microbiota (e.g., genera *Bifidobacterium*, *Lactobacillus*, and *Escherichia*) are able to release them [8]. Moreover, flavonoid glycosides are deconjugated by microbial glucuronidases and sulfatases in the colon, releasing aglycones such as quercetin, myricetin, and kaempferol that can be metabolized by different genera of intestinal bacteria, including *Clostridium* sp., *Eubacterium* sp., *Enterococcus* sp., among others, to form hydroxyphenylacetic and hydroxyphenylpropionic acids as major metabolites leading to increased bioavailability of phenolic compounds [24].

Chickpea, pea, and bean seeds are among the most widely consumed food legumes worldwide. The genus *Cicer* comprises about 44 species. The chickpea (*Cicer arietinum* L.) has two commercial varieties ‘Desi’ and ‘Kabuli’ and their characteristics vary according to geographical distribution, shape, size, and color. The color of the Desi variety is dark in comparison with the Kabuli chickpea, which has a fine, light-colored covering and is the most widely consumed [20, 23].

Pisum sativum L., commonly known as pea, represents one of the oldest and most widespread cultivated legumes worldwide due to its wide availability, low cost, and high nutritional value [1, 16], they are small seeds with a green or yellow spherical shape. Quality characteristics depend on biological factors between the environment and genetics [25]. Another important legume in food is the genus *Phaseolus*, which includes species such as *P. vulgaris*, *P. lunatus*, *P. coccineus*, *P. acutifolius*, and *P. dumosus*; among these, the most cultivated in Mexico is the common bean (*P. vulgaris*) that has more than 70 varieties grouped according to their color in black, yellow, red, brown, white, purple, and pinto [14, 26, 27].

Phenolic compounds constitute an important group of secondary plant metabolites and influence the diversity and quantity of gut microbial species, allotting prebiotic effects to phenolic compounds, mainly flavonoids involved in modulating the taxonomic composition of the gut microbiota, increasing the relative abundance of beneficial species, and inhibiting the proliferation of bacterial species associated with negative implications [7, 24].

2. Phenolic compounds in chickpea, pea, and common bean: chemistry, distribution, and beneficial effects

Legumes are an excellent source of phytochemicals, including phenolic acids, flavonols, flavones, flavanols, flavanones, isoflavones, anthocyanins, tannins, and other phenolics [14, 16, 28, 29]. The structure of polyphenols and their composition and interaction in a food matrix are important determinants of their bioavailability and bioactivity [12, 15, 30]. **Figure 1** shows the structures of phenolic compounds present in chickpea, pea, and bean. Differences in the phenolic profile of various legumes influence the specific health benefits. The presence of phenolic acids and flavonoids in legumes such as chickpea, pea, and beans have been reported in different units of concentration and are presented in **Table 1**.

Phenolic compounds are present in soluble and insoluble forms. Therefore, it is very important to optimize the polyphenols extraction process [9, 10]. Most of the phenolic compounds associated with whole seed are in insoluble bound forms, mainly phenolic acids, linked covalently to cell wall structural components like cellulose, hemicellulose, lignin, and pectin [14, 20, 30, 45].

Chickpea contains several phenolic compounds, including lignans (secoisolariciresinol, pinoresinol, and lariciresinol), isoflavones, flavonoids, phenolic acids, and anthocyanins [20, 49]. Besides, it has significant amounts of flavonoids, especially isoflavones, the main ones being biochanin A and formononetin, to a lesser extent genistein and daidzein [5, 9, 12, 47].

The main compounds in peas are glycosylated flavonols, condensed tannins, as well as hydroxybenzoic and hydroxycinnamic acids, such as quercetin, kaempferol, luteolin, apigenin, flavan-3-ols, apigenin-7-glucoside, quercetin-3-rhamnoside, kaempferol-3-glucoside, flavonols, flavones, and stilbenes; the main compounds identified in the whole seed are hesperidin and catechin [26, 47]. In beans, phenolic acids and flavonoids represent 50% of the total content of phenolic compounds like vanillic, ferulic, 4-hydroxybenzoic, sinapic acids; quercetin, myricetin, and catechin are the major phenolic acids contained in bean seeds and determine the seed color [10, 14, 28].

Figure 1.
 Main phenolic compounds in legumes [20, 28, 31].

Compound	Concentration (DW)			References
	Chickpea	Pea	Bean	
Phenolic acids				
<i>p</i> -Hydroxybenzoic acid	10.5 ^b /0.08–1.63 ^c	588.94 ^a	0.30-16.30 ^b	[20, 31–34]
Protocatechuic acid	358.9 ^b /0.51 ^c	426.15 ^a /0.89-2.25 ^d	0.42-37.36 ^b /170-177 ^c	[20, 31–33, 35–37]
Syringic acid	222.1 ^b /0.63–1.95 ^c	nd	10.60-11.40 ^c	[20, 31, 34, 38]
Vanillic acid	80.8 ^b /0.34 ^c	536.67 ^a	618.44 ^b	[20, 31, 33, 36, 39]
Gallic acid	40.2 ^b /4.66 ^c	218.45 ^a /9.08-29.95 ^d	0.15–21.30 ^c	[20, 31, 33–35, 40]
Ellagic acid	0.43 ^c	433.87 ^a /899.19 ^c	4.3-18.08 ^b	[20, 33, 41–43]
Caffeic acid	0.11 ^c	146.11 ^a /0.20–0.92 ^d	3.08-11.70 ^b	[20, 33, 35, 36, 42]
Chlorogenic acid	nd	742.28 ^a /0.57–1.27 ^d	3.03-33.38 ^b /6.63-46.1 ^c	[33–37, 40, 42, 44]
<i>p</i> -coumaric acid	0.11 ^c	462.93 ^a /7.78 ^c /9.0-16.2 ^d	0.40-1.90 ^b /0.74 ^c	[20, 33, 40, 41, 44–46]
Ferulic acid	0.90 ^b /0.22 ^c	788.29 ^a /1.38-3.44 ^d	0.91-11.00 ^b	[20, 31, 33, 35, 36, 44, 46]
Sinapic acid	7.81 ^b /0.12 ^d	nd	2.9-86.27 ^b	[20, 31, 32, 39, 46]
Flavonoids				
Quercetin	nd	56.90 ^c /0.12-1.51 ^d	0.8-30.88 ^b /0.30-1.31 ^c	[33–35, 39, 40, 44, 46]
Quercetrin	nd	256.26 ^c	1.07 ^c	[33, 40]
Myricetin	nd	nd	1.99–5.98 ^b	[43, 44, 46]
Kaempferol	0.09 ^b	19.79 ^c	2.51 ^b /0.13 ^c	[33, 40, 44, 46, 47]
Rutin	0.101 ^c	83.01 ^c /0.26-1.31 ^d	0.20-119.70 ^c	[33–35, 37, 40]
Naringenin	nd	24.59 ^c	nd	[33]
Naringin	nd	201.41 ^c	2.35 ^c	[33, 40]
Hesperidin	nd	605.94 ^c	8.10 ^c	[33, 40]
Hespirtin	nd	158.29 ^c	0.56 ^c	[33, 40]
Catechin	nd	93-2303 ^d	10.05-78.34 ^b	[32, 39, 43–45]
Epicatechin	nd	1.03–13.02 ^d	10.90-34.48 ^b	[35, 42, 43]
Luteolin	1.56 ^b	3.24-8.57 ^d	2.41 ^c	[31, 35, 40]
Apigenin	nd	14.31 ^c	nd	[33]
Genistein	0.06 ^c	nd	3.64-4.74 ^c	[37, 48]
Daidzein	0.12 ^c	nd	nd	[48]
Formononetin	0.02 ^b /0.10 ^c	nd	35.94-163.34 ^b	[43, 47, 48]

Compound	Concentration (DW)			References
	Chickpea	Pea	Bean	
Biochanin A	0.78 ^b	nd	nd	[47]
Biochanin glucoside	0.08 ^c	nd	nd	[48]
Biochanin A derivative	3.31–5.25 ^b	nd	nd	[47]

^appm.
^bµg/g.
^cmg/100 g.
^dmg/kg.
^emg/g.
DW: Dry weight, nd: not detected.

Table 1.
Polyphenols reported in chickpea (C. arietinum), pea (P. sativum) and common bean (P. vulgaris) seeds.

The phenolic composition of legumes has been particularly interesting for metabolic health because of their protection against oxidative damage [45]. Phenolic compounds constitute an important group of secondary plant metabolites, important for health by preventing multiple degenerative conditions in the body [16]. These compounds are biologically active and have been associated with antidiabetic, anticarcinogenic, antihypertensive, antimutagenic, antioxidant, antimicrobial, anti-inflammatory, anticholesterolemic, cardioprotective, immunostimulant, and anti-angiogenic properties [11, 14, 16, 20, 21, 29, 35, 41, 49, 50].

3. Impact of processing on phenolic compounds

Processing of legumes may result in an increase or decrease in the content of phenolic compounds. During processing, phenolic compounds may undergo various changes, altering the antioxidant activity of the products. Changes in phenolic content depend on the species, variety, and processing conditions [12, 18, 22]. Processes such as soaking, cooking, extrusion, germination, fermentation, and roasting improve the release of bound phenolic compounds, which influences the sensory properties of the seeds [51–54].

During processing, a reduction in the content of condensed tannins has been reported. In legumes, soaking has been found to decrease tannic acid content by approximately 20%, and germination reduces tannin content by 50%. The decrease of phenolic compounds during soaking and cooking may be due to several factors during the heat treatment, such as 1) polyphenol-protein interactions that decrease the extraction capacity, 2) the formation of tannin complexes with other water-soluble components, and 3) the lixiviation and thermal degradation of phenolic compounds [12, 14, 30]. However, unlike traditional processing or pressure cooking, the extrusion process is carried out in the absence of effluents, so the impact on phenolic content is less [52, 55, 56]. Arribas et al. [55] observed that extrusion does not affect the phenolic groups to the same extent; they reported that the anthocyanin content in extruded pea decreased from 4 to 50% as opposed to the flavonol content, which increased approximately three times.

On the other hand, the germination process increases bioactive compounds, like phenolic compounds, improving the seeds functionality. The increase is attributed to biosynthesis through the Shikimate pathway and the release of phenolic compounds. During germination, enzymatic reactions are activated, such as the enzyme phenylalanine ammonia lyase, which promote the phenolic compounds'

biosynthesis. The endogenous esterases action allows the liberation of hydroxycinnamic acids linked to arabinoxylans and lignin in the cell wall [20, 57, 58]. Nevertheless, changes in isoflavones during this process may be related to genetic regulation. They may be induced by the metabolic pathways of naringenin chalcone and isoliquiritigenin, the precursors of isoflavonoids, present in legumes. Therefore, germination is an efficient alternative to increase antioxidant activity and has been used in legumes such as chickpeas, peas, and beans [9, 12, 48, 50]. Domínguez-Arispuro et al. [20] observed that the germination process in chickpeas induced an increase of 97 and 111% of the total phenolic and flavonoid content, respectively, as compared to the raw seed. Moreover, formononetin and biochanin contents of 0.10 and 0.18 mg/g, respectively, have been reported in raw chickpea; during a 10-day germination process, they increased to 1.42 and 2.10 mg/g respectively [48].

The fermentation process has been reported to cause an increase in free radical scavenging capacity. Changes in phenolic composition are associated with sensory, nutritional, and biochemical properties and depend on fermentation conditions such as optimal time and temperature to avoid a further reduction, mainly in tannin content [53, 59, 60]. Bulbula & Urga [53] reported the effect of different traditional processing methods on tannins in chickpea, noting that during boiling, toasting, and fermentation at 0 h, there are no differences from raw seed beans. However, during fermentation for 24, 48, 72 h and chickpea germination, tannin content decreased by 3.1, 14.4, 18.5, and 43.4%, respectively. The reduction of tannins during germination is generally attributed to enzymatic hydrolysis by polyphenolase.

4. Impact of phenolic compounds on the gut health and its relationship with human health

The gut microbiota plays an important role in food digestion, immunity, and other metabolic functions; its composition is influenced by endogenous and environmental factors such as age, diet, lifestyle, antibiotic intake, and xenobiotics. Optimal gut health depends on the microbial community structure, a balanced composition of gut microbiota, an epithelial barrier, and an intact host mucosa; therefore, a disorder of these components can lead to the development of intestinal diseases such as obesity, inflammatory bowel disease, and colon cancer [1–3, 6, 7, 21, 22, 24, 49, 61].

Legumes are composed of bioactive compounds, such as phenolic compounds, capable of modifying the physiological basal function within the intestinal microenvironment affecting the microbiota and epithelial barrier, improving metabolic and gastrointestinal health, enhancing resistance to colonization by pathogens, and exerting an impact on the gut microbiota. These actions lead to decrease the severity of diseases associated with the intestine due to their chemopreventive effects. However, not all polyphenols support gastrointestinal integrity equally, and their benefits depend on chemical structure and phenolic concentration [12, 21, 31, 49, 62]. Isoflavones, such as biochanin A, have been reported to improve gut health by exerting antioxidant and anti-inflammatory effects [12, 20, 21]. On the other hand, the effect of formononetin in an acute colitis model in mice induced by dextran sulfate sodium has been evaluated, observing an attenuation of colitis. This effect may be due to the inhibition of the NLRP3 inflammasome pathway by the action of formononetin [9].

Bian et al. [2] suggest that kaempferol has a protective effect on the secretion of interleukin-8 (IL-8) and the barrier dysfunction of the Caco-2 monolayer in the lipopolysaccharide-induced epithelial-endothelial co-culture model. This effect is due to the inhibition of the nuclear factor-kappa B (NF- κ B) signaling pathway,

which allows the reduction of inflammatory bowel disease. Also, caffeic acid reduces the secretion of pro-inflammatory cytokines, including interleukin-6 (IL-6), tumor necrosis factor- α (TNF- α), and IFN γ , and colonic infiltration of CD3+ T cells, CD177+ neutrophils, and F4/80+ macrophages by inhibiting the activation of the NF- κ B signaling pathway [63]. Naringin is a flavonoid that has a beneficial effect on intestinal disorders. Liu et al. [64] showed that naringin (50 μ M) protects the integrity of rat intestinal microvascular endothelial cell monolayer barriers against TNF- α -induced disruption, preventing TNF- α -induced apoptosis and suppressing cell migration, and avoiding gut-vascular barrier disruption. Moreover, the proanthocyanidins or condensed tannins have been reported to have bioactive properties like anti-inflammatory and antimicrobial, causing a reduction in intestinal inflammation and promoting the growth of *Lactobacillus* spp. and *Bifidobacteria* spp. [1, 62].

Recent animal studies have shown that chickpeas consumption improves gut health by inhibiting the proliferation of cancer cells, attenuating inflammation, modulating the composition and activity of the microbiome, promoting epithelial barrier integrity, mucus production, and antimicrobial defenses [49, 65]. In addition, the quantitative structure–activity relationship on the cytotoxic effect of

Figure 2.
The potential prebiotic effect of anthocyanins on gut microbiota and obesity. SCFA: Short-chain fatty acids; FIAF: Fasting-induced adipose factor; LPS: Lipopolysaccharide; ZO-1: Zonula occludens-1; IR: Insulin resistance. Anthocyanins and metabolites formed in the intestine change the composition of the gut microbiota. This is associated with restored tight-junction protein (ZO-1 and occludin) distribution, and localization. Hence, the gut permeability is decreased, and plasma lipopolysaccharide (LPS) levels (metabolic endotoxemia) are lowered, improving low-grade inflammation and obesity-related comorbidities. Anthocyanins decrease transcription factor NF- κ B activity in the cell nucleus by decreasing gene expression of inflammatory cytokines, exerting their anti-inflammatory action. Anthocyanins have the ability to promote the growth of *Bifidobacterium* spp., which increases the intestinal production of FIAF that inhibits fat storage in the host. *Bifidobacterium* spp. degrade SCFA; propionate stimulates mucus secretion and contributes to thickening of the mucus layer. At the same time, reduced mucus layer thickness favors microbiota encroachment. The figure is taken from [15].

phenolic compounds have been studied. The *p*-hydroxybenzoic acid present in *P. sativum* exhibits strong cytotoxic activity in the colon carcinoma (HCT116) cell line [33]. Additional clinical evidence suggests that bean intake may reduce the incidence of developing advanced colorectal adenoma in humans [66]. Chen et al. [67] noted that cyanidin-3-*O*-glucoside protects against intestinal mucosal damage caused by 3-chloro-1, 2-propanediol (3-MCPD), a food contaminant. **Figure 2** shows the prebiotic effect of anthocyanins on the gut microbiota.

5. Phenolic compounds during gastrointestinal digestion: bioaccessibility and bioavailability

Bioaccessibility is defined from a nutritional point of view as the fraction of compounds liberated from the food matrix within the human gastrointestinal tract and available for intestinal absorption. The gastrointestinal tract is prone to oxidative stress due to its function as a primary digestive system and exposure to various stimuli [15, 29, 67]. The bioaccessibility and bioavailability of several phenolic compounds have been studied, noting that the aglycones in isoflavones are more bioavailable than their conjugated counterparts [9]. The absorption and bioavailability of phenolic compounds are commonly affected by low solubility, low permeability, and low stability in the gastrointestinal tract [29]. Some researchers have suggested that 5–20% of the total polyphenol content in legumes can be absorbed. The preventive action provided by these compounds depends on bioaccessibility. However, in the case of chronic diseases, such as stomach and colorectal cancer, they do not depend on the polyphenols bioaccessibility; still, gut microbiota can increase the bioavailability of the phenolic content of foods and quadruple their antioxidant activity [9, 12, 15, 29, 67].

5.1 Oral cavity absorption

During oral digestion, the food matrix is broken down, allowing phenolic compounds and other nutrients to be released into the environment due to enzymatic hydrolysis by salivary α -amylase. However, the decrease in polyphenols such as condensed tannins during mastication is due to the interaction with salivary proteins resulting in insoluble aggregates [50]. Luzardo-Ocampo et al. [68] indicated that the antioxidant activity of bean methanolic extracts during *in vitro* gastrointestinal digestion increases in the mouth stage due to a higher release of certain polyphenols such as catechin, chlorogenic acid, and vanillin. As gastrointestinal digestion progresses, antioxidant activity is increased until it reaches the large intestine, where it decreases.

5.2 Gastric absorption

Polyphenols are very poorly absorbed after ingestion and remain in the gastrointestinal tract, where they influence digestive enzymes activity, inhibiting crucial enzymes involved in the digestion of starch (α -amylase), lipids (pancreatic lipase), and protein digestibility (pepsin and trypsin). Digestibility is influenced by the polyphenol's interaction with food and endogenous proteins, like digestive enzymes, salivary proteins, gastric and intestinal mucosa, and other endogenous proteins on the luminal side of the intestinal tract [16, 69, 70]. Studies with *in vitro* simulation revealed that during gastric digestion (pH 1.2–2.0 in the presence of pepsin), there is a decrease in the recovery of phenolic compounds because they can interact with the pectin present in the food [29]. However, the presence of (+)-catechin has been evidenced in the stomach stage due to resistance to the acid environment [68].

5.3 Intestinal absorption

Polyphenols are not completely absorbed in the small intestine (5–10%). More than 90% enter the large intestine and are fermented by the human colon microbiota interacting with microorganisms (10–14 bacterial cells) and enzymes (α -L-rhamnosidase and β -D-glucosidase). Fermentation facilitates the liberation and absorption of insoluble bound phenolics involved in colorectal cancer prevention. The degradation of phenolic acids by enteric bacterial or chemical conversions may produce other metabolites, including protocatechuic acid, syringic acid, vanillic acid, phloroglucinol aldehyde, phloroglucinol acid, and gallic acid [3, 9, 15, 20, 21, 24, 30, 63, 69].

Phenolic compounds are catabolized by the gut microbiota, originate common phenolic (e.g., daidzein to equol, flavan-3-ols to valerolactones, and ellagitannins to urolithins) intermediates as in phenylpropionic, phenylacetic, and benzoic acids with different degrees of hydroxylation [17]. The flavonoids present in bound form (glycosides) and in free form (aglycones) are changed during digestion; a low fraction of these glycosides can be enzymatically hydrolyzed to aglycones in the small intestine, causing these aglycones to be more hydrophobic compared to the original glycosides. Aglycones are absorbed by epithelial cells through passive diffusion and then transported to the liver, where they will be metabolized. However, flavonoid glycosides are hardly absorbed in the small intestine due to their hydrophilic nature and reach the large intestine intact, where they will be metabolized by the gut microbiota [24].

During intestinal digestion, polyphenols such as anthocyanins, phenolic acids, catechin, quercetin, resveratrol, and rutin are unstable in the alkaline environment intestinal fluid (pH 6.8–8.0) due to their degradation [29]. The main phenolic acids absorbed in the small intestine are gallic, caffeic, and ferulic acids [63, 68]. Luzardo-Ocampo et al. [68] observed that phenolic acids in beans, like ferulic, chlorogenic, and vanillin, do not change their content during their passage through the small intestine, for 60–120 min, indicating their resistance to the intestinal enzymes and allowing them to arrive at the large intestine for fermentation. Milán-Noris et al. [12] observed that chickpea cooking increased intestinal absorption of the existent isoflavones. On the other hand, Cárdenas-Castro et al. [54] evaluated the bioaccessibility and *in vitro* release kinetics of phenolic compounds from two varieties of beans (Azufrado and Negro Jamapa). These authors reported that in cooked beans, the phenolic compounds showed 50% bioaccessibility, and 30% in cooked-fried beans, indicating that cooking did not modify the release kinetics of phenolic compounds during the first 60 min, being kaempferol-3-*O*-glucoside, quercetin-3-*O*-glucoside, and chlorogenic acid the main compounds released.

6. Interactions of phenolic compounds with the gut microbiota: metabolism and modulation

The interaction between the gut microbiota and the diet components is fundamental to the promotion of gut health. Lignans, flavonoids, and other phenolic compounds present in legumes participate in the modulation of the host's mucosal barrier integrity, attenuate the inflammatory process associated with colitis, and improve epithelial barrier integrity, aside from modulating fecal and cecal microbiota composition and providing beneficial effects against metabolic diseases like obesity. The interaction of gut microbiota and phenolic compounds, mainly anthocyanins, can implicate hydrolysis, demethylation, reduction, decarboxylation, dehydroxylation, or isomerization of compounds into simpler components

to modulate absorption [15, 21, 49, 69]. Chlorogenic acid is poorly absorbed in the small intestine, but it has been shown that the bioavailability of this compound depends on the metabolism of the gut microflora. However, when this compound is metabolized in the colon, it modulates the colonic microbiota inducing a significant increase in the growth of *Bifidobacterium* spp. and *Clostridium coccooides-Eubacterium rectale*, revealing a potent antimicrobial activity by binding and permeabilizing the bacterial cell membrane [63]. On the other hand, it has been shown that phenolic compounds present in cooked chickpeas, like quercetin, daidzein, biochanin A, and formononetin, improved the integrity of the intestinal barrier by reducing its permeability and providing antioxidant and anti-inflammatory effects that promote gut health and decrease pathologies, like colitis [21, 49].

7. Conclusion

The inclusion of legumes such as chickpeas, peas and beans in the diet has increased consumer health benefits due to their content of bioactive compounds such as phenolic compounds and other nutrients. During digestion, these compounds are not completely absorbed in the intestinal tract and are metabolized in the colon, increasing their bioaccessibility and bioavailability. These compounds have been shown to participate in the modulation of the gut microbiota, the epithelial barrier and resistance to pathogen colonization, improving gut health by inhibiting the proliferation of cancer cells through their chemopreventive effects. The impact of phenolic compounds on the gut microbiota suggests that the incorporation of legumes into the diet and the design of novel functional foods may improve human health by preventing the development of metabolic and gastrointestinal disorders, including irritable bowel syndrome, inflammatory bowel disease, obesity, diabetes, colitis, and colorectal cancer. However, further research should be conducted to understand the impact of phenolic compounds during digestion and gut microbiota modulation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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