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Effects of Different Processing Methods on Pulses Phytochemicals: An Overview

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ABSTRACT

Pulses are edible seeds belonging to the Leguminosae family for human consumption and consist of various species such as common beans (*Phaseolus vulgaris* L.), peas (*Pisum sativum*), lentils (*Lens culinaris*), chickpeas (*Cicer arietinum* L.), and faba beans (*Vicia faba*). Pulses are sustainable sources of nutritional compounds, especially containing almost twice the protein content compared to cereal grains. In addition to becoming an excellent source of macronutrients and micronutrients, they are abundant in phytochemicals, containing bioactive compounds with potential health benefits resulting from various phenolic compounds, as well as antinutritional compounds (e.g. phytic acid, enzyme inhibitors, lectins, saponins), which have received widespread concern by researchers. More essentially, various processing approaches for consumption purposes will result not only in enhanced nutritional and sensory characteristics in pulses but also in affected phytochemicals contents and their bioavailability. In this review, the nutritional and phytochemical compositions of pulses will be first introduced, followed by different common-applied processing methods (thermal and non-thermal), along with their impacts and pulse storage effects on the content of corresponding phytochemicals. Furthermore, through food processing and digestion, the bioaccessibility and bioavailability of pulse phytochemicals will be improved, thus releasing more health benefits, and expressing pharmacological functions in the human body.

KEYWORDS

Pulses; phytochemicals; phenolic compounds; antinutrients; processing; bioaccessibility

Introduction

Pulses are a subclass of legumes, which are included in the *Leguminosae* family that yield edible seeds for human and animal consumption.[1] Pulses consist of various species, including the common beans (*Phaseolus vulgaris* L.), peas (*Pisum sativum*), chickpeas (*Cicer arietinum* L.), cowpeas (*Vigna unguiculata*), lentils (*Lens culinaris*), faba beans (*Vicia faba*), pigeon peas (*Cajanus cajan*), as well as some others, in terms of worldwide production and consumption, are dominant.[2,3] Typically, their consumption forms involve whole seeds, split grains, dehulled split grains, and flour, thus meeting different needs for consumers.[2]

According to FAO statistics, the average annual consumption of pulses per person was projected to be between 2.7 and 10.8 kg in 2011.[4] The share of different regions globally in the production of significant pulses is different (Table 1). Even though pulses are grown everywhere in the world, almost half of it is concentrated in South Asia and sub-Saharan Africa.[2] Besides, the dominant importing

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Table 1. Pulse classification, production, consumption, and diets.

Pulse Classification	Annual global production (million tons/year)	Major exporting countries	Major importing countries	Pulse consumption	References
Common beans (*Phaseolus vulgaris* L.)	25.66*	China, Myanmar, USA, Argentina, Canada, etc.	India, Mexico, USA, UK, Brazil, etc.	Traditional household diets: Fried, baked, or cooked to be eaten as veggies; Commercial processing and products: Packaged dry beans, canned beans, precooked bean products, extruded and pasta-like products, specialised food ingredients (meals, flours, concentrates, powders, and flakes), quick-cooking beans, and frozen beans.	[5,6]
Common Peas (*Pisum sativum*)	11.69	Canada, Russian Federation, USA, France, Australia, etc.	India, China, Bangladesh, Pakistan, Belgium, etc.	Fresh peas cooked as a side dish vegetable and flavoured with butter, spearmint, or both; Used in pot pies, salads, and casseroles; When harvested within a few hours, pod peas best kept by drying, canning, or freezing; Used in stir-fried dishes, notably those in American Chinese cuisine.	[2,6]
Chickpeas (*Cicer arietinum* L.)	11.67	Australia, Russian Federation, India, Mexico, Canada, etc.	India, Bangladesh, Pakistan, United Arab Emirates, Algeria, etc.	Boiled, consumed raw, roasted, dehulled, or processed to make flour; Popular snacks after roasted.	[6–9]
Cowpeas (*Vigna unguiculata* L.)	6.50	Nigeria, Niger, Burkina Faso, United Republic of Tanzania, Cameroon, etc.	USA	Traditional diets: Eaten whole, cooked, or prepared into stews and soups; Commercial processing methods: Boiling/roasting, milling/fractioning, germination/fermentation.	[6,10–12]
Faba beans (*Vicia faba*)	4.47	Australia, UK, Lithuania, Egypt, Latvia, etc.	Egypt, Norway, Germany, Saudi Arabia, France, etc.	Typical treatments and processing techniques: Dehulling, soaking, germination, fermentation, extrusion heating, and enzyme treatment; Traditional goods, pasta/spaghetti, bread, tofu, yoghurt, and other foods are examples of processing products.	[6,13]
Lentils (*Lens culinaris*)	4.99	Canada, Australia, Turkey, USA, etc.	India, Turkey, Bangladesh, Sri Lanka, United Arab Emirates, etc.	Macrosperma variants are consumed predominantly in West Asia, North Africa, and Europe as whole grain; Microsperma types, are consumed primarily in Asia in dehulled and split form.	[2,6]
Pigeon peas (*Cajanus cajan*)	4.45	India, Myanmar, Malawi, Kenya, Uganda, etc.	Mauritius	Major processing methods: Shelling, freezing, and canning; Specific procedures in pigeon pea canning and freezing: Cleaning, blanching, and filling cans or polythene bags.	[5,6,11,14]
Other pulses	6.25	-	-	-	[6]
Total pulses	75.68	-	-	Varied in individual diet forms and common processing ways; Consumption methods and most staple dishes prepared from pulses could be various; The combination of pulse and cereal proteins serve a balanced nutrition; Pulses and pulse products (e.g., pulse flour) can be utilized as gluten-free diets to improve nutrition for populations with special demands (e.g., celiac disease).	[15–17]

* The data for annual global production of pulses (million tons/year) are according to 2013–2017 statistics.

countries of different classes of pulses are different. While the pulse production scale is relatively tiny compared to cereal output, their annual average yield has been rising for years.[7] The annual global production of pulses had increased to almost 77 million metric tonnes in three years ending in 2014, amounting to over 2.8% of global cereal production. From the perspective of global pulse production (according to 2014 statistics), common beans ranked first among all major pulse species (31.2%) and chickpeas ranked second (16.9%), subsequently followed by peas (14.3%), cowpeas (9.1%) and other species.[2]

Pulses are generally recognized as a vital ingredient for human nutrition and health.[5] Due to their high protein content (considerably higher than that of cereals), dietary fibre, starch, minerals, and vitamins, pulses have become a staple food and inexpensive source of protein in developing nations where protein-energy malnutrition (PEM) is common. Low-income groups of people especially prefer pulses because of their high protein quality. Due to the large regional differences, in several countries, pulses have become an essential dietary constituent, including Kenya (17.0 per person annually), India (15.4 per person annually), and Turkey (13.6 per person annually).[7] In addition, in terms of the amino acid profile, cereal proteins could supply their abundant methionine and cysteine, which pulses lack. In contrast, pulses could contribute with their richer lysine which cereals lack.[7] Therefore, especially for vegetarians, a complete complement of amino acids (or plant-based diets), and balanced nutrition, can be achieved through the combination of pulse and cereal proteins.[18] Moreover, pulses and pulse products such as pulse flour can be utilized as gluten-free diets to improve nutrition for populations with unique demands (e.g., celiac disease).[17]

Pulse is not only rich in nutritional compounds but also various phytochemicals, including phenolic compounds, alkaloids, phytosterols, saponins, enzyme inhibitors, and others. These phytochemicals are also related to health benefits, including anti-obesity, antidiabetic, anti-inflammatory, and antioxidant potential.[19–21] In addition, various processing methods have been applied to produce pulse and pulse-based products due to storage and nutrient enhancement needs. However, individual processing methods have different specific influences on pulse phytochemicals, including their contents, bioaccessibility, and bioavailability. Therefore, this review aims to provide pulse nutritional composition along with a phytochemical profile, including bioactive compounds and antinutrient compounds. Meanwhile, different processing effects on pulse phytochemicals, the bioaccessibility, bioavailability, as well as health benefits on the human body, will be summarized.

Nutritional composition of pulses

As demonstrated in Table 2, pulses are abundant in various nutritional compounds. Primarily, they provide a rich source of protein with contents of 19–30%.[18] The protein composition of the pea, lentil, and chickpea is comparable to that of cowpeas and beans.[18] Albumins (<20%) and globulins (>50%) are the two dominant types of proteins found in pulses. Depending on the pulse species, lower amounts of glutelin and prolamins are found. Pulses also contain necessary amino acids like lysine, cysteine, and methionine.[18] Pulses are rich in the amino acid lysine; however, cereal grains are frequently deficient in this amino acid. At the same time, pulses have low levels of the vital amino acids methionine and tryptophan, which can be presented in products made from grains.[15] As a result, pulses and grain-based products complement each other when consumed with cereal to offer a higher quality protein.

Relatively low in energy density, pulses after the cooking process provide a 1.3 kcal/g average.[15] They have a higher carbohydrate content (up to 50%–65%) but are absorbed more slowly, giving them a lower glycemic index (GI) than other carb-rich meals like rice, white bread, or potatoes.[56] Insoluble and soluble dietary fibre are both abundant in pulses, which offer about 7 g per half-cup serving, while the amount varies depending on the pulse species.[41]

According to Hall, et al.,[18] pulses typically have a lipid content less than 3%, whereas chickpea and lupin can have as high as 7% and 13%, respectively. In terms of the lipid fraction of pulses, it is characterized by a high level of triglycerides, along with a higher concentration of monounsaturated fatty acids (oleic acid, C 18:1n-9) and polyunsaturated fatty acids (linoleic acid, C 18:2n-6, and alpha-linoleic acid C 18:3n-3) that are both beneficial components.[57] Recent research has revealed an intriguing *n*-6/n-3 PUFA ratio, emphasizing lentils and azuki beans with values of 4.0 and 3.2, respectively, which provide health benefits like lowered CVD risk.[58]

Further, pulses are a good source of micronutrients, containing various minerals and vitamins.[59] They include B-group vitamins, such as thiamine, niacin, folate, riboflavin, and pyridoxine, and are an excellent source of selenium.[15] Moreover, pulses are a good origin of iron and zinc. For instance, a half-cup portion of beans contains over 10% of the daily recommended amount of iron, even though the amount in different types of beans might vary significantly.[60]

Phytochemical composition of pulses

According to Neilson, et al.,[61] plant bioactive compounds are dominantly secondary metabolites, which means they are not necessary for plant organisms' survival. In detail, secondary metabolites include specific substances that give the plant advantages in survival and competition. Besides, "natural products" or "phytochemicals" are other names for plant secondary metabolites. Alkaloids, terpenoids, as well as phenolics/polyphenols, are the three main types of phytochemicals found in plants. Minor classes possess polyacetylenes, miscellaneous pigments, cyanogenic glucosides, glucosinolates, and nonprotein amino acids. As summarized in Table 3, pulses enrich various bioactive compounds, such as phenolic compounds, phytosterols, and non-digestible carbohydrates, all of which have essential physiological and metabolic effects.[103] Many recent reviews also address the main phytochemical compounds in different pulses.[103,104]

As one of the dominant groups of pulses' bioactive compounds, the aromatic rings of phenolic compounds have one or more hydroxyl substituents, resulting in simple to highly complex polymers.[105] They have a broad therapeutic potential attributed to their antioxidant capabilities, which are due to their ability to act as reducing agents, hydrogen donors, and neutralizers of free radicals according to their ox-reduction potential.[106] The primary phenolic components found in pulse seeds are condensed tannins, phenolic acids, and flavonoids, which are classified as flavanols, flavan-3-ols, and anthocyanins.[103] Besides, phenolic acids discovered in pulses are either cinnamic acid (e.g., caffeic, ferulic, sinapic, and *p*-coumaric acid) or benzoic acid (e.g., gallic, syringic, and vanillic acid) derivatives, found as esters of caffeic and quinic acids.[42] Flavonoids share the diphenylpropanes (C6-C3-C6) structure, consisting of two aromatic rings connected by three carbons and typically forming an oxygenated heterocycle.[107] Isoflavones, in which the B ring of the flavone molecule is connected to carbon 3, are particularly common in pulses. While tannins are highly hydroxylated, forming insoluble complexes with proteins and carbohydrates.

Field bean (*Vicia faba*) hulls have been measured to contain condensed tannins (proanthocyanidins), which are also found in the seeds of coloured-flowered cultivars of peas.[108] Further, the phenolic compositions in pulses are primarily found in the seed coat, while the cotyledon part has comparatively minor concentrations.[103] Regarding the common bean, phenolic compounds are primarily found in the seed coat. The presence of flavonol glycosides, anthocyanins, and condensed tannins is principally responsible for the seed colour. Hou, et al.[109] also concluded that the abundance of phenolic compounds present in pulse seed coats was highest in common beans, followed by lentils and peas, while least in mung bean and lupin. Additionally, pulses with a deep colour and a lot of pigment, including black gram (*Vigna mungo*) and red kidney beans (*Phaseolus vulgaris*), are indicated with higher phenolic concentrations.[110,111] The total phenolic content (TPC) also varies among different pulse varieties. For instance, in Xu, et al.[112] study, the lentils and kidney bean samples (47.6 and 45.7 mg/g DW, respectively) showed the highest phenolic content, while lima bean showed the lowest (9.5 mg/g DW).

A group of incredibly diverse substances known as alkaloids typically consist of a heterocycle with a nitrogen atom inside the cycle. This confirmation gives the molecule a primary character; in an

Table 2. Nutritional composition of different pulse sources (raw/unprocessed seeds).

Nutritional Compounds			Pulse Source	Content (Per 100 g dry weight)	Reference
Macronutrients					
Protein			Common beans	16.7–27.2 g/100 g	[22]
			Peas	20.5–22.6 g/100 g	[18,23–27]
			Chickpeas	20.47 g/100 g	[28,29]
			Cowpeas	22.5–26.1 g/100 g	[12,30]
			Faba bean	26.12–29.2 g/100 g	[13,31]
			Lentils	20.6–31.4 g/100 g	[32]
	Total essential amino acids		Common beans	33.64–40.42 g·16 g−1 N	[33]
			Lupine (blue, white, yellow, andean)	35.53–37.61 g·16 g−1 N	[34]
			Pea	38.59 g·16 g−1 N	
			Chickpea	40.55 g·16 g−1 N	
			Lentil	39.59 g·16 g−1 N	
			Chickpea (flour)	39.89 g/100 g proteins	
	Individual essentail amino acids	Lysine	Common beans	1.24 g/100 g	[22]
				5.46–6.33 g·16 g−1 N	[33]
			Cowpeas	3.5–7.9 g·16 g−1 N	[35]
			Peas	6.67 g·16 g−1 N	[33]
			Chickpeas	6.60 g·16 g−1 N	
			Lentil	6.92 g·16 g−1 N	
			Lupine (blue, white, yellow, andean)	5.57–6.81 g·16 g−1 N	
			Chickpea (flour)	6.00 g/100 g proteins	[34]
		Leucine	Common beans	1.68 g/100 g	[22]
			Chickpea (flour)	7.59 g/100 g proteins	[34]
			Faba beans	21.4 g/kg	[36]
			Peas	17.4 g/kg	
			Lupines (*Lupinus Albus*, *Lupinus Angustifolius*, *Lupinus luteus*)	21.5–27.5 g/kg M	
		Phenylalanine	Common beans	1.36 g/100 g	[22]
			Chickpea (flour)	5.57 g/100 g proteins	[34]
			Faba beans	12.6 g/kg	[36]

(*Continued*)

Table 2. (Continued).

Nutritional Compounds			Pulse Source	Content (Per 100 g dry weight)	Reference
			Peas	11.7 g/kg	
			Lupines (*Lupinus Albus*, *Lupinus Angustifolius*, *Lupinus luteus*)	12.5–14.9 g/kg	
		Valine	Common beans	1.01 g/100 g	[22]
			Chickpea (flour)	5.60 g/100 g proteins	[34]
			Faba beans	13.3 g/kg	[36]
			Peas	11.4 g/kg	
			Lupines (*Lupinus Albus*, *Lupinus Angustifolius*, *Lupinus luteus*)	12.5–14.5 g/kg	
		Methionine	Chickpea (flour)	1.54 g/100 g proteins	[34]
		Cysteine	Chickpea (flour)	1.36 g/100 g proteins	
		Tyrosine	Chickpea (flour)	3.58 g/100 g proteins	
		Threonine	Chickpea (flour)	3.86 g/100 g proteins	
		Isoleucine	Chickpea (flour)	4.76 g/100 g proteins	
Carbohydrate			Common beans	51.51–57.19 g/100 g	[37]
			Peas	17–22 g/100 g	[38,39]
			Chickpea	62.95 g/100 g	[29]
			Cowpeas	74.8 g/100 g	[30]
			Faba bean	44.1 g/100 g	[31]
			Lentils	43.4–69.9 g/100 g	[32]
	Dietary fiber		Common beans	27.8–34.78 g/100 g	[40]
			Peas	14–26 g/100 g	[41–45]
			Chickpeas	6.49–12.2 g/100 g	[29,46]
			Cowpea	10.6 g/100 g	[12]
			Faba bean	25 g/100 g	[13]
			Lentils	5.0–26.9 g/100 g	[32]
		Soluble Dietary Fiber	Common beans	0.3–1.6 g/100 g	[47]
			Chickpeas	1.23–1.38 g/100 g	[48]
		Non-Soluble Dietary Fiber	Common beans	25.2–36.1 g/100 g	[47]

(*Continued*)

Table 2. (Continued).

Nutritional Compounds			Pulse Source	Content (Per 100 g dry weight)	Reference
			Chickpeas	14.15–23.18 g/100 g	[48]
		Total Starch	Common beans (Negro 8025, Pinto Durango)	35.27–39.84 g/100 g	[47,49]
			Peas	20–50 g/100 g	[25,50]
			Chickpea	36.91g/100 g	[28]
			Cowpeas	28.3–36.2 g/100 g	[51]
			Faba bean	41.2–44.3 g/100 g	[52]
			Lentils	44.5 g/100 g	[15]
		Total Sugars	Common beans (white bean, broad bean)	2.8–5.9 g/100 g	[15]
			Peas	3.87–15.1 g/100 g	[53]
			Chickpeas	10.7 g/100 g	[29]
			Cowpea	6.90 g/100 g	[12]
			Lentils	1.2 g/100 g	[15]
		Glucose	Peas	0.90 g/100 g	[53]
			Chickpeas	0–0.065 g/100 g	[28,54]
		Sucrose (g)	Peas	2.20–4.20 mg/g d.w	[53]
			Chickpeas	1.09–2.28 g/100 g	[28,54]
		Fructose (g)	Chickpeas	0.23–0.28 g/100 g	[28,54]
Total lipid (Fat)			Common beans (white bean, broad bean)	0.9–2.1 g/100 g	[15]
			Peas	2.34–2.65 g/100 g	[53]
			Chickpeas	4.64–5.68 g/100 g	[48]
			Cowpeas	1.26–1.9 g/100 g	[12,51]
			Faba bean	1.53–2.0 g/100 g	[13,52]
			Lentils	0.7–4.3 g/100 g	[32]
	Saturated fatty acids (SFA)		Common beans	0.300–0.490 g/100 g	[15,22]
			Cowpeas	25.1–90.3 g/100 g	[35]
			Lentils	0.2 g/100 g	[15]
	Monounsaturated fatty acids (MUFA)		Common beans	0.230–0.400 g/100 g	[15,22]
			Cowpeas	7.5–24.0 g/100 g	[35]
			Lentils	0.3 g/100 g	[15]
	Polyunsaturated fatty acids (PUFA)		Common beans	0.500–1.280 g/100 g	[15,22]
			Cowpeas	32.4–64.8 g/100 g	[35]
			Lentils	0.8 g/100 g	[15]

(*Continued*)

Table 2. (Continued).

Nutritional Compounds		Pulse Source	Content (Per 100 g dry weight)	Reference
	Water	Common beans (white bean, broad bean)	11.0–11.3 mg/100 g	[15]
Micronutrients				
Minerals	Calcium (Ca)	Common beans (white bean, broad bean)	100–180 mg/100 g	[15]
		Peas	9.5 mg/100 g	[55]
		Chickpeas	81.7–165 mg/100 g	[48]
		Cowpeas	34.7 mg/100 g	[30]
		Faba bean	103–220 mg/100 g	[13,31]
		Lentils	71 mg/100 g	[15]
		Pegion peas	120.8 mg/100 g	
	Iron (Fe)	Common beans	5.500–8.082 mg/100 g	[15]
		Peas	2.20–49.0 mg/100 g	[55]
		Chickpeas	4.31–5.50 mg/100 g	[29,48]
		Cowpeas	8.27 mg/100 g	[12]
		Faba bean	6.6–6.7 mg/100 g	[13,31]
		Lentils	11.1 mg/100 g	[15]
	Magnesium (Mg)	Common beans (white bean, broad bean)	180–190 mg/100 g	[15]
		Peas	5.5 mg/100 g	[55]
		Chickpeas	147.0–169 mg/100 g	[48]
		Cowpeas	184 mg/100 g	[12]
		Faba bean	192–281 mg/100 g	[13,31]
		Lentils	110 mg/100 g	[15]
	Potassium (K)	Common beans (white bean, broad bean)	1090–1160 mg/100 g	[15]
		Peas	98 mg/100 g	[55]
		Chickpeas	994.5–1060.0 mg/100 g	[48]
		Cowpeas	1112 mg/100 g	[12]
		Faba bean	748–1062 mg/100 g	[13,31]
		Lentils	940 mg/100 g	[15]
	Phosphorus (P)	Common beans (white bean, broad bean)	310–590 mg/100 g	[15]
		Peas	0.22–0.51 mg/100 g	[55]
		Chickpeas	252–451.5 mg/100 g	[29,48]
		Cowpeas	424 mg/100 g	[12]

(*Continued*)

Table 2. (Continued).

Nutritional Compounds		Pulse Source	Content (Per 100 g dry weight)	Reference
		Faba bean	421 mg/100 g	[13]
		Lentils	350 mg/100 g	[15]
	Zinc (Zn)	Common beans (white bean, broad bean)	2.229–3.768 mg/100 g	[15]
		Peas	2.04–6.35 mg/100 g	[55]
		Chickpeas	3.4–4.07 mg/100 g	[48]
		Cowpeas	3.37 mg/100 g	[12]
		Faba bean	3.14–11.7 mg/100 g	[13,31]
		Lentils	3.9 mg/100 g	[15]
	Sodium (Na)	Common beans (white bean, broad bean)	11-43mg/100 g	[15]
		Peas	3.5 mg/100 g	[55]
		Cowpeas	16 mg/100 g	[12]
		Faba bean	13–297 mg/100 g	[13,31]
		Lentil	12 mg/100 g	[15]
	Selenium (Se)	Cowpeas	9.0 mg/100 g	[12]
Vitamin	Thiamin (Vitamin B1)	Common beans (white bean, broad bean)	0.45–0.5 mg/100 g	[15]
		Peas	0.44–0.62 mg/100 g	[53]
		Chickpeas	0.477 mg/100 g	[29]
		Faba bean	0.64 mg/100 g	[31]
		Lentils	0.41 mg/100 g	[15]
	Riboflavin (Vitamin B2)	Common beans (white bean, broad bean)	0.13–0.26 mg/100 g	[15]
		Peas	0.07–0.64 mg/100 g	[53]
		Chickpeas	0.212 mg/100 g	[29]
		Faba bean	0.190 mg/100 g	[31]
		Lentils	0.27 mg/100 g	[15]
	Niacin	Peas	1.06 mg/100 g	[53]
		Chickpeas	1.541 mg/100 g	[29]
		Cowpeas	2.06 mg/100 g	[12]
		Faba bean	2.000–2.832 mg/100 g	[13,31]
	Pyridoxine (Vitamin B6)	Common beans (white bean, broad bean)	0.37–0.56 mg/100 g	[15]
		Peas	0.10 mg/100 g	[53]
		Chickpeas	0.535 mg/100 g	[29]
		Faba bean	0.230 mg/100 g	[31]

(*Continued*)

Table 2. (Continued).

Nutritional Compounds	Pulse Source	Content (Per 100 g dry weight)	Reference
	Lentils	0.93 mg/100 g	
Pantothenic acid	Chickpeas	1.588 mg/100 g	[29]
	Cowpeas	1.50 mg/100 g	[12]
	Faba bean	0.270 mg/100 g	[31]
Choline	Chickpeas	99.3 mg/100 g	[29]
	Cowpeas	94.7 mg/100 g	[12]
Folate/Folic acid (Vitamin B9)	Peas	0.050–0.054 mg/100 g	[53]
	Chickpeas	0.557 mg/100 g	[29]
	Cowpeas	0.633 mg/100 g	[12]
	Faba bean	0.423 mg/100 g	[13]
Retinol (Vitamin A)	Common beans (white bean, broad bean)	0 g	[15]
	Chickpeas	67 IU	[29]
	Cowpeas	3 µg/100 g	[12]
	Lentils	0g	[15]
	Faba bean	53 IU	[13]
Ascorbic acid (Vitamin C)	Common beans (white bean, broad bean)	Tr	[15]
	Peas	2.2–29.5 mg/100 g	[53]
	Chickpeas	4.0 mg/100 g	[29]
	Cowpeas	1.50 mg/100 g	[12]
	Faba bean	1.4 mg/100 g	[13]
	Lentil	Tr	[15]
Tocopherol (Vitamin E)	Common beans (white bean, broad bean)	0.21 mg/100 g	[15]
	Peas	2.2–7.1 mg/100g	[53]
	Chickpeas	2.88 mg/100 g	[15]
Phylloquinone (Vitamin K)	Faba bean	9 mg/100 g	[13]

* Tr stands for trace.

aqueous solution, the molecule tends to pick up a proton unless the nitrogen atom is adjacent to an electron acceptor (e.g. ricinine).[42] Lupins possess the majority of them (i.e., lupanine, lupinine, sparteine, and multiflorine), but developing alkaloid-free variants has boosted the number of lupins in fodder for domestic cattle.[113] Additionally, alkaloids were reported to be present in peas as well as in tiny amounts in chickpeas and lentils.[57] Lupanine has recently been identified to increase insulin secretion, as reported by Wiedemann, et al.[114]; as a result, it may be relevant for the supportive treatment of diabetes mellitus.

In addition to being significant bioactive components of pulses, phytosterols, plant sterols, and stanols are the equivalent ingredients to cholesterol present in mammals.[115] These compounds attach to bile acids and stop them from being reabsorbed.[103]

Pulses contain trace amounts of phytosterols, the most prevalent of which are β-sitosterol, campesterol, and stigmasterol.[116] The pulses have a total phytosterol concentration that ranges from 134 mg/100 g (kidney bean) to 242 mg/100 g (pea), as Ryan, et al.[86] studied. Total β-sitosterol content ranged between 85 mg/100 g in butter beans and 160 mg/100 g in chickpeas.[86]

Many other bioactive phytochemicals have been reported in pulses. For instance, pulses contain higher oligosaccharides compared to other crops; among them, α-galactosides are the dominant ones, including raffinose, stachyose, and verbascose.[117] Based on Han and Baik[118] investigation, total oligosaccharides in different pulses ranged between 70.7 mg/g DW (in yellow pea seeds) and 144.9 mg/g DW (in chickpea seeds).

Additionally, they include more significant levels of inaccessible or indigestible carbohydrates, such as resistant starch and dietary fiber, leading to a lower glycemic index (GI). Furthermore, pulses contain tocopherol with higher antioxidant potential (up to 52 mg/100 g in lupine seeds as reported).[18]

Anti-nutritional compounds

Pulses contain various antinutritional compounds, including protease inhibitors, lectins, phytic acid, saponins, condensed tannins, and others, which can reduce the bioavailability and digestibility of other nutritional compounds and exceptionally, could be the cause of diseases.[119] Protease inhibitors (such as trypsin and chymotrypsin) and amylase inhibitors are the two most common enzyme inhibitors of pulses (Table 3). Proteases, amylases, lipases, glycosidases, and phosphatases can be inhibited by protein hydrolases found in pulses.[120] Common beans (*Phaseolus vulgaris*) are the second-largest group of plant seeds after cereals that have been identified as natural sources of alpha-amylase inhibitors, which decreases the utilization of dietary starch and protein, potentially acting as a treatment for diabetes while also reducing the digestibility of dietary proteins.[121] In addition, protease inhibitors also suppress the digestibility and bioavailability of nutrients.[120]

Most plant foods include lectins or haemagglutinins, and pulses are the primary source of lectins in daily meals for humans. There have been reports of kidney beans showing a high level of lectins (840×10^{-5} hemagglutinating activity units (HU)/kg) and lupin seeds having a relatively low level (3×10^{-5} HU/kg).[122] Due to some lectins disrupting the integrity of the intestinal epithelium, which affects the absorption and utilization of nutrients, some pulses' lectins decrease the growth of experimental animals and diminish the digestibility and biological value of dietary proteins.[123]

According to Martín-Cabrejas,[57] pulses store phosphorus mainly in the form of phytic acid (IP6), which can account for 3–5% of their total phosphorus content. Since phytic acid is a potent chelating agent and decreases the bioavailability of primarily divalent cations like Zn^{2+}, Fe^{2+}, Mn^{2+}, Mg^{2+}, and Ca^{2+}, it is regarded as a non-nutritive component. Insoluble metal-phytic complexes are generated under the digestive tract, decreasing their digestive use and subsequent assimilation in both animals and people. Along with interfering with digestive enzymes like pepsin, trypsin, and α-amylase, IP6 can also interact with proteins to produce phytate-protein complexes that impair the solubility and digestibility of dietary proteins.[124] Based on Oomah, et al.,[125] phytic acid makes up an average of 83% of all inositol phosphates, with the percentage varying from 77% in chickpea to 88% in black

Table 3. Contents of phytochemicals in different pulse sources.

Phytochemicals	Pulse Source	Content	Reference
Phenolic Compounds			
Total Phenolics	Mexican Common beans	0.90–2.11 mg GAE/g	[62]
	Common beans (Black, Pinto, Red)	8.58–20.30 mg catechin/g	[63]
	Peas	4.90 mg CE/g *d.w.	[64]
	Peas (flour)	5.89 mg CE/g d.w	[65]
	Lentils	11.8–12.0 mg/g	[66]
	Chickpeas	2.2 mg/g	
	Peas (Yellow Peas, Green Peas)	1.2–2.5 mg/g	
	Soybeans	2.3 mg/g	
	Cowpea	7.94 mg GAE/g	[67]
	Cowpeas	89.4–295.2 mg GAE/g	[68]
	Faba bean	220.55 µg GAE/g	[69]
	Faba bean (Seeds)	3.86 mg GAE/g d.w	[70]
	Faba bean (Leaves)	43.18–54.31 mg GAE/g d.w	
	Faba bean (10 varieties)	258–570 mg GAE/100 g d.w.	[71]
	Lentils (5 different genotypes)	5.90 mg GAE/g	[72]
	Pigeon pea	0.16%	[73]
		3.82%-16.61%	[74]
		6.15 mg GAE/g	[75]
Total Phenolic Acids	Peas (Yellow peas, Green peas)	154.4–253.3 mg/g	[76]
	Chickpeas	1285.7 mg/g	
	Lentil	2818.6 mg/g	
	Chickpeas	16.92–36.91 µg/g	[77]
	White lupine	508.6 µg/100 g	[78]
Hydroxybenzoics	Pinta beans	84.92 µg/g	[79]
	Peas (Yellow peas, Green peas)	74.91–84.38 mg/g	[76]
	Chickpeas	165.6 mg/g	
	Lentil	136.1 mg/g	
	Chickpeas (Sinaloa chickpea, Castellano chickpea)	7.05–25.62 µg/g d.w.	[80]
	Faba Beans (10 varieties)	76.2–153.9 µg/g	[71]
Hydroxycinnamics	Pinta beans	36.31 µg/g	[79]

(*Continued*)

Table 3. (Continued).

Phytochemicals	Pulse Source	Content	Reference
	Peas (Yellow peas, Green peas)	79.46–168.9 mg/g	[76]
	Chickpeas	1120.2 mg/g	
	Lentil	2682.5 mg/g	
	Faba beans (10 varieties)	3.37–7.71 µg/g	[71]
Total Flavonoids	Common Bean	5.03–14.12 mg quercetin/g	[81]
	Chickpeas	148.48–302.09 µg/g	[77]
	Cowpeas	109.0–164.0 mg QE/g1	[68]
	Faba beans	106.33µg QE/g	[69]
	Faba bean (Seeds)	1.00mg CE/g d.w.	[70]
	Faba bean (Leaves)	43.68–63.67mg CE/g d.w.	
	Faba bean (10 varieties)	200–316 µg/g	[71]
	Lentils	398.33 mg catechin/100 g	[82]
	Lentils (5 different genotypes)	4.95mg CATE/g	[72]
	Pigeon peas	2.11–5.44%	[74]
	Pigeon peas	43.43 QE/100 g	[75]
Flavonols	Pinta beans	14.58 µg/g	[79]
	Common Beans (Black, Pinto, Red)	0.22–1.11 µg QE/g	[63]
	Peas	0.08 µg QE/g	[64]
	Pea (flour)	81.54 µg QE/g d.w.	[65]
	Chickpeas (Sinaloa chickpea)	1.83 µg/g d.w.	[80]
Total flavan-3-ols	Peas (Yellow peas, Green peas)	205.3–282.9 mg/g	[76]
	Chickpeas	1693.7 mg/g	
	Lentil	4524.9 mg/g	
Flavanones	Pinta beans	10.87 µg/g	[79]
Isoflavones	Chickpeas (Sinaloa chickpea, Castellano chickpea)	51.92–57.53 µg/g d.w.	[80]
Tannins	Common Bean	10.1–44.2 mg CE/g	[83]
	Lupine (Blue, White, Yellow, Andean)	2.58–16.34 g/kg	[33]
	Peas	4.69 g/kg	
	Chickpea	3.78 g/kg	
	Lentil	8.72 g/kg	
	Common Bean	0.38–1.53 g/kg	
	Faba Beans (5 selected cultivars)	0.21–0.65 mg/g	[84]

(*Continued*)

Table 3. (Continued).

Phytochemicals	Pulse Source	Content	Reference
	Lentils	466.10 mg/100 g	[82]
	Lentils (5 different genotypes)	3.04 mg GAE/g	[72]
	Pigeon Pea	0.22–0.49%	[73,74]
Condensed Tannins	Common Bean	2.15–10.65 mg catechin/g	[81]
	Cowpeas	1.9–4.9 mg catechin/g	[68]
	Mexican Common Bean	9.49–35.70 mg of catechin/g	[62]
Anthocyanins	Common Bean	0.43 ± 0.03 mg cyanidin 3-gluc./g	[81]
	Mexican Common Bean	0.01–1.85 mg of cyanidin 3-glucoside (C3G)/g	[62]
	Common Beans (Red, Pinto, Black)	0.32–0.63 mg cyanidin-3-glucoside equivalent/g	[63]
	Peas	80.00 μg C3GlcE/g d.w.	[64]
	Peas (flour)	8.21 μg C3GlcE/g d.w.	[65]
	Cowpeas	0.1–1.8 mg cy-3-glu–1	[68]
Catechins and procyanidins	Pinta beans	256.94 μg/g	[79]
Catechin	Chickpeas	123.64–225.76 μg/g	[77]
	Faba beans	1455.59 μg/g	[69]
Total proanthocyanidin	Faba Beans (5 selected cultivars)	0.162–0.271 mg/g	[84]
	Lentils (5 genotypes)	7.93 mg PCBE/g	[72]
Other Bioactive Compounds			
Oligosaccharide	Mexican Common Bean	39.0–57.6 mg/g	[85]
Total α-galactosides	Pea	71.45 mg/g d.w.	[64]
	Pea (flour)	6.43 mg/100 mg d.w.	[65]
Total Phytosterols	Lentils	22.9–31.6 mg/100 g	[78]
	Peas (Yellow Split, Green Split)	33.7–42.8 mg/100 g	
	Chickpeas	48.9 mg/100 g	
	Kidney Bean	134 mg/100 g	[86]
	Pea	242 mg/100 g	
β-sitosterol	Butter Bean	85 mg/100 g	[86]
	Chickpea	160 mg/100 g	
Alkaloid	Pigeon pea	0.323–2.65%	[73,74]
Total tocopherol (Ts)	Chickpeas	90.50–120.95 μg/g	[77]
		124.5 mg/100 g	[87]

(*Continued*)

Table 3. (Continued).

Phytochemicals	Pulse Source	Content	Reference
Total carotenoid	Chickpeas	111.0 mg/100 g	[87]
Resistant Starch	Mung Bean	5.70–5.95 g/100 g	[88]
	Cowpea	3.24–9.62 g/100 g	
Antinutritional Compounds			
Phytic Acid	Chickpeas	21.2 mg/g	[89]
	Faba bean	32.0 mg/g	[89]
	Chickpea (*desi* and *kabuli* cultivars)	Varied from 5.98 (*kabuli* PUSA1053) to 11.00 (*desi* JG74) mg/g	[90]
	Black gram (*Vigna mungo* (L.) Hepper)	5.6 mg/g (varied from 1.7 (KUG-365)-9.0 (KUG-509) mg/g)	[91]
	Lentils	4.13 mg/g (brown lentils, after household cooking), 7.14 mg/g (Green lentils, after canning)	[92]
Total inositol phosphates (IP)	Peas	11.08 mg/g	[64]
Phytate	Peas	8.82 mg/g	[64]
	Pigeon pea	1.017%	[73]
Trypsin Inhibitor	Chickpeas	14.7 mg/g	[89]
	Faba bean	2.2 mg/g	[89]
	Faba beans (Whole, Split)	5.96 (Whole faba bean)–6.10 (Split faba bean) TIU/mg	[93]
	Chickpea (*desi* and *kabuli* cultivars)	Varied from 17 to 31 mg/g in *desi* cultivars and in 9 to 16 mg/g in *kabuli*	[90]
	Chickpeas	14.22–16.24 TIU/mg	[93]
	Black gram (*Vigna mungo* (L.) Hepper)	94.2 units/g seeds	[91]
	Lentils (Whole red lentil, Split red lentil, Football red lentil, Spanish brown lentil, etc.)	4.98–6.29 TIU/mg	[93]
	Lentils	0.94–1.94 TIU/mg	[94]
	Peas (Whole yellow pea, Split yellow pea, Whole green pea, Split green pea)	3.16–4.92 TIU/mg	[93]
	Common beans (Dark red kidney bean, Pinto bean, Navy bean, Black bean)	15.18–20.83 TIU/mg	[93]
	Soybean	45.89 TIU/mg	[93]
	Common Bean	6.3–14.5 TUI/mg	[83]
	Peas	9.43 TIU/mg	[64]
α-Amylase inhibitor	Dry beans	43.19%	[63]
	Bean (Dark red kidney bean, Pinto bean, Navy bean, Black bean)	Varied from 785.58 (Black bean) to 1369.75 (Dark red kidney bean) AIU/g dry matter	[93]
	Soybean	938.73 AIU/g dry matter	[93]

(*Continued*)

Table 3. (Continued).

Phytochemicals	Pulse Source	Content	Reference
Chymotrypsin inhibitor	Peas	3.17 CIU/mg	[64]
Total Tannins	Faba bean	1.28 g/100 g	[89]
	Chickpea (*desi* and *kabuli* cultivars)	Varied from 0.18 to 0.22% in *desi*; 0.07 to 0.13% in *kabuli*	[90]
	Black gram (*Vigna mungo* (L.) Hepper)	7.33 mg/g	[91]
Saponins	Faba beans (VH 131 variety)	13.70 mg/g	[95]
	Black gram (*Vigna mungo* (L.) Hepper)	14.3 mg/g	[91]
	Pigeon pea	21.64 mg/g- 34.94 mg/g	[96]
	Pigeon pea	0.466%	[73]
Total soyasaponins	Mexican black bean	42.28 mg/100 g	[97]
Oxalate	Pigeon pea	0.139%	[73]
Total polyphenols	Faba beans	14.70 mg/100 g d.w.	[98]
	Chickpea	1.47–2.87 mg GAE/g d.w.	[99]
	Lentils (Small lentils, large lentils)	25.8 (Large lentils)-25.9 (Small lentils) mg GAE/g	[100]
	Lentils (Colfiorito lentils, Eston lentils, Dehulled lentils, Laird lentils, Black lentils, etc.)	0.84–4.52 mg GAE/g	[101]
	Lentils	37.14 mg/100 g d.w.	[98]
	Lentil	1.22–7.45 mg GAE/g d.w.	[99]
	Peas (Green split peas, Yellow split peas)	11.8–13.6 mg GAE/100 g fresh w.t.	[100]
	Common beans	0.68–7.16 mg GAE/g	[101]
	Lupines (White lupines)	19.4 mg GAE/100 g fresh w.t.	[100]
Lectin/Haemagglutinins	Common Bean	0.5–3.1 HAU/g	[83]
	Peas	83.33 HU/kg	[64]
	Kidney Beans	840 ×10−5 HU/kg	[102]
	Cowpea	3×10−5 HU/kg	
	Lupin	3×10−5 HU/kg	

*d.w.: dry weight.

beans. Additionally, it tends to be present in larger concentrations in raw dry beans, black eye pea, and pigeon pea than in lentil, green split pea, and chickpea. On the other hand, pulses also contain significant amounts of phytate, the salt form of phytic acid found in the endosperm's protein bodies.

Saponins are another typical group of antinutritional compounds widely distributed in various pulses, such as chickpea, soybean, lentil, phaseolus bean, and the alfalfa sprout.[42] The primary sources of saponins in the human diet are indicated as soybean and chickpea.[125] Moreover, saponins can reduce the availability of nutrients and limit enzyme activity, which can have a growth-retarding effect on animal growth.[126]

Furthermore, other antinutritional components in pulses include oxalates (which can lower mineral bioavailability like phytates), phenolic compounds (including isoflavones), condensed tannins (which decrease food intake in animals), lignans (phyto-estrogens), and lignins (which reduce fermentability of dietary fibres), among others.[42]

Effect of processing on pulse phytochemicals

Through various thermal and non-thermal processing methods, the phytochemical compounds in pulses can be influenced, particularly in terms of phenolic compounds and antinutritional compounds. Thermal processing can quickly eliminate partial heat-labile antinutritional factors, such as protease inhibitors and lectins.[119] In contrast, other antinutritional compounds, such as phytic acid, tannins, and saponins, withstand heat. Coda, et al.[127] concluded that dehulling, soaking, air classification, extrusion, and cooking are the primary technological methods for reducing the adverse effects of antinutritional compounds on pulse consumption. However, biological techniques tend to be more effective, including germination, enzyme treatments, and particularly fermentation. In the following sub-sections, various thermal and non-thermal processing methods and their effects on phytochemical profiles and contents in pulse seeds will be introduced (Table 4).

Soaking

As one basic processing approach, soaking can soften the cell walls of the pulse seeds, thus facilitating the subsequent cooking process.[177] The concentration of relevant phytochemical compounds will hence be influenced by soaking processing. Primarily, due to pertinent chemicals seeping into the soaking water during this stage, polyphenols will become soluble and lose their potency, thus causing a reduced general content of total phenolic contents (TPC).[177] For example, Xu and Chang[76] reported a 4.9–11.5% reduction in TPC in green peas and 9.5–37.8% in lentils after the soaking process (50, 70, 85, 100% hydration). Similar decreasing trends in TPC in five soaked different faba bean cultivars were also observed by Siah, et al..[167] Secondly, soaking can remarkedly influence the levels of certain phenolic compounds. Soaking pulses can effectively reduce the tannin content due to the diffusion effect into the water.[178] Alonso, et al.[129] reported a reduction of 47.7% and 24.2% in condensed tannin content in faba bean and kidney bean, respectively; Khandelwal, et al.[136] also reported around 22% reduction in total tannins in red gram and Bengal

However, some studies showed the reverse effects of soaking on pulse phenolic compounds. Lentils were shown to contain more dihydroxybenzoic acid after being soaked, rising from 3.68 μg/g to 39.20 μg/g.[135] And it was also demonstrated by Aguilera, et al.[179] that flavonols in Sinaloa chickpea were increased by the soaking process. Not only soaking alone but also soaking with cooking on the different phenolic compounds has been studied and reported. Luthria and Pastor-Corrales[180] observed that while overnight soaking samples showed a considerable loss in total phenolic acids, following cooking of bean samples retained more than 83% of the total phenolic acids.

Soaking of pulse seeds causes the reduction of phytate and phytic acid in general, mainly attributed to its water solubility, seeping into the soaking water, as well as the endogenous phytase activation.[181] Khattab and Arntfield[130] investigated the phytic acid of studied pulses (Canadian and Egyptian cowpea, kidney bean, and pea) reduced significantly after soaking. Shimelis and Rakshit[131] illustrated that compared to the raw control, soaked kidney beans had a 14–18% reduction in phytic acid.

Moreover, soaking can significantly influence the level of other antinutrient and bioactive compounds. The soaking process results in the aqueous extraction of saponins because of their high water solubility.[182] For instance, as Sharma and Sehgal[137] reported, two of the faba bean cultivars that were studied had a 20–23% drop in saponins after soaking for 12 hours at 37°C. In addition, as for pulses, soaking can lower the concentration and activities of enzyme inhibitors such as trypsin, α-amylase, and chymotrypsin inhibitors.[93] This phenomenon might be resulted from relevant inhibitors leaking into soaking water during treatment.[183] In Shi, et al.[93] study, after soaking, the level of α-amylase inhibitor in common beans was reduced by 4–10%, and that in soybean decreased by 4%. Simultaneously, trypsin inhibitor was significantly reduced by soaking in studied pea (17.34–30.74%), lentil (5.57–19.35%), faba bean (12.73–22.59%), chickpea (9.39–25.27%), common bean (4.88–9.09%), and soybeans (18.58%). Moreover, soaking also causes reduction of other phytochemicals, such as oligosaccharides (sucrose, stachyose and raffinose) in soybean, cowpea and ground bean samples.[184]

Extrusion

Utilizing the mix of moisture, pressure, temperature, and mechanical shear, extrusion processing creates food products with distinctive physical and chemical properties, along with shortened cooking time and enhanced textural, nutritional, dietary, and sensory attributes of food ingredients at the same time.[185] Tas and Shah[186] indicated that incorporating pulse-based flours into extruded cereal-based snacks exerts better nutritional benefits (e.g., high protein and dietary fibre, low fat, elevated resistant starch levels) and functional properties (e.g., sensory appeal, textural attributes).

Extrusion can not only enhance the digestibility of starch and protein but also significantly impact the elimination of antinutritional factors, including trypsin inhibitors, lectins, phytic acid, and tannin.[187,188] As shown in Table 4, Alonso, et al.[129] indicated that the best treatment for removing trypsin, chymotrypsin, α-amylase inhibitors, and hemagglutinin activity without changing the protein composition was extrusion processing. Rathod and Annapure[189] extruded lentils (18% moisture, 160°C, 200 rpm), and discovered that the final product had trypsin inhibitor, phytate, and tannin concentrations that had been reduced by up to 99.54, 99.30, and 98.83%, respectively. Besides, according to Pasqualone, et al.,[190] observed a remarkable decrease in trypsin inhibitor levels after extrusion and attributed this result to heat and intense mechanical stress. Moreover, trypsin inhibitors can be significantly inactivated and destructed by extrusion at higher temperatures or by lengthening the residence period when extruding at lower temperatures.[191]

The impact of extrusion cooking on different groups of phenolic compounds may vary. Several studies have proved the significant reduction of total phenolic compounds in extruded pea, kidney bean, faba bean, and chickpea.[129,139,192] The excessively high temperatures may cause the unfavorable effects of extrusion cooking on relevant phenolic compounds.[193] On the other hand, some experiments reported increasing reverse impacts. In Arribas, et al.[194] study, an increase in total phenolics and anthocyanins was observed in the extrudates made from pea, rice, and carob flour. It was demonstrated that if phenolics are mostly bound to dietary fibre in the cell walls in the starting flour, as they are in carob, then the extrusion process will tend to partially disrupt the fibre, thus releasing relevant phenolic compounds.[195,196]

Furthermore, some other phytochemical compounds can also be affected during the extrusion process. For instance, when compared to raw materials, extrusion cooking led to a considerable increase in the concentration of total α-galactosides of up to 85%.[141] Lentil extrudates produced at 160°C had a greater total α-galactoside concentration than those produced at 140°C.[141] This might be related to the fact that oligosaccharides are relatively heat-stable.[197] Therefore, during the extrusion procedure, the cell walls undergo mechanical-structural changes, which may enhance their availability in the final extrudates.[190] However, few studies indicate that extrusion processing affects vitamins'

Table 4. Effect of different processing methods on pulse phytochemical compounds.

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Soaking				
Faba bean	Phytic acid	Raw	8.36 mg/g	[128]
		Soaking (10°C, after preheating)	4.10–5.35 mg/g (36–51% decreased)	
		Natural and accelerated fermentation	1.34–4.34 mg/g (48–84% decreased)	
		Steeping (25°C, 24 h)	6.12–6.86 mg/g (18–27% decreased)	
		Sprouting (30°C, 120 h)	2.66–7.70 mg/g (8–69% decreased)	
Faba beans	Condensed tannins	Raw	1.95 g eq cat kt−1 DM	[129]
		Soaking	1.02 g eq cat kt−1 DM (47.7% decreased)	
Canadian cowpea	Phytic acid	Raw	22.63 mg/g	[130]
		Soaking (18 h)	14.71 mg/g	
		Boiling (4 h)	6.30 mg/g	
Kidney bean (Roba variety)	Phytic acid	Unprocessed seeds (control)	23.51 mg/g	[131]
		Water soaking (12 h in plain water)	19.28 mg/g (18% decreased)	
		Sodium bicarbonate soaking (12 h)	20.22 mg/g (14% decreased)	
	Tannins	Unprocessed seeds (control)	5.37 mg/g	
		Water soaking (12 h in plain water)	4.03 mg/g (25% decreased)	
		Sodium bicarbonate soaking (12 h)	3.92 mg/g (27% decreased)	
Kidney beans	Condensed tannins	Raw	3.59 g eq cat kt−1 DM	[129]
		Soaking	2.72 g eq cat kt−1 DM (24.2% decreased)	
Black bean (*T*-39 cultivar)		Raw	47.1 mg/100 g	[132]
		Soaking (Soaking water extract)	0.9 mg/100 g	
		Cooking (Paste of simmered beans)	38.2 mg/100 g	
Great Northern bean (Matterhon cultivar)	Total phenolic acid content	Raw	32.5 mg/100 g	[132]
		Soaking (Soaking water extract)	0.2 mg/100 g	
		Cooking (Paste of simmered beans)	32.2 mg/100 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Vegetable peas (Bonneville)	Phytic acid	Control	630.3 mg/100 g	[133]
		Soaking (6 h)	598.7 mg/100 g	
		Soaking (12 h)	581.3 mg/100 g	
		Soaking (18 h)	554.6 mg/100 g	
Green pea	TPC	Raw	1.22 mg GAE/g	[134]
		Soaking (50, 70, 85, 100% hydration).	1.08–1.16 mg GAE/g (4.9–11.5% decreased)	
Lentils	TPC	Raw	7.34 mg GAE/g	[134]
		Soaking (50, 70, 85, 100% hydration).	4.56–6.64 mg GAE/g (9.5–37.8% decreased)	
Pardina Lentil	kaempferol 3-glucoside	Raw	3.66 µg/g	[135]
		Soaking	2.21 µg/g	
	dihydroxybenzoic acid	Raw	3.68 µg/g	
		Soaking	39.20 µg/g	
Sinaloa chickpea	*p*-hydroxybenzoic acid	Raw	6.01 µg/g dry matter	[80]
		Soaking	1.88 µg/g dry matter (68.7% decreased)	
	Total flavonols	Raw	1.83 µg/g dry matter	
		Soaking	3.40 µg/g dry matter (increased)	
		Soaking + cooking	2.78 µg/g dry matter (increased)	
	dihydroxybenzoic acid	Raw	0.44 µg/g dry matter	
		Soaking	0.35 µg/g dry matter	
		Soaking + cooking	3.50 µg/g dry matter (increased)	
Red gram	Tannins	Raw	296.9 mg/100 g	[136]
		Soaking	230.1 mg/100 g (22.5% decreased)	
Bengal gram	Tannins	Raw	236.6 mg/100 g	[136]
		Soaking	184.3 mg/100 g (22.1% decreased)	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Faba beans (Two varieties)	Saponins	Soaking (12 h, 37°C)	20–23% decreased	[137]
Common beans	α-amylase inhibitor	Soaking	4–10% decreased	[93]
Soybean	α-amylase inhibitor	Soaking	4% decreased	
Peas	Trypsin inhibitor	Soaking	17.34–30.74% decreased	
Lentils	Trypsin inhibitor	Soaking	5.57–19.35% decreased	
Faba beans	Trypsin inhibitor	Soaking	12.73–22.59% decreased	
Chickpeas	Trypsin inhibitor	Soaking	9.39–25.27% decreased	
Common beans	Trypsin inhibitor	Soaking	4.88–9.09% decreased	
Soybean	Trypsin inhibitor	Soaking	18.58% decreased	
Pulse	Cyanogenic glycosides	Soaking (sodium bicarbonate solution)	13.9% decreased	[138]
		Soaking (citric acid solution)	8.7% decreased	
		Soaking (water)	7.7% decreased	
Extrusion				
Faba beans	Phytic acid	Raw (unsoaked)	6.40 mg/g	[139]
		Extrusion (Unsoaked; 140°C and 180°C; 18% and 22% moisture)	6.86 mg/g (140°C, 18%); 6.05 mg/g (180°C, 22%); 6.26 mg/g (140°C, 22%); 6.23 mg/g (180°C,18%).	
		Raw (pre-soaked)	6.10 mg/g	
		Extrusion (pre-soaked)	4.80–5.50 mg/g	
	Tannins	Raw (unsoaked)	492 mg/100 g	
		Extrusion (unsoaked)	397–438 mg/100 g	
		Raw (pre-soaked)	485 mg/100 g	
		Extrusion (pre-soaked)	362–426 mg/100 g	
	Total phenols	Raw (unsoaked)	850 mg/100 g	
		Extrusion (unsoaked)	635–750 mg/100 g	
		Raw (pre-soaked)	810 mg/100 g	
		Extrusion (pre-soaked)	559–644 mg/100 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Faba beans	Phytic acid	Raw	21.7g/kg DM	[129]
		Extrusion	15.9 g/kg DM (26.6% decreased)	
	Condensed tannins	Raw	1.95 g eq cat/kt DM	
		Extrusion	0.89 g eq cat/kt DM (54.4% decreased)	
	Polyphenols	Raw	3.92 g/kg DM	
		Extrusion	2.80 g/kg DM (28.6% decreased)	
	Trypsin inhibitors	Raw	4.47 IU/mg DM	
		Extrusion	0.05 IU/mg DM (98.9% decreased)	
	Chymotrypsin inhibitor	Raw	3.56 IU/mg DM	
		Extrusion	1.68 IU/mg DM (52.8% decreased)	
	α-Amylase inhibitors	Raw	18.9 IU/g DM	
		Extrusion	0.00 IU/g DM (100% decreased)	
	Hemagglutinating activity	Raw	49.3 HU/mg DM	
		Extrusion	0.2 HU/mg DM (99.6% decreased)	
Peas	Phytic acid	Raw (Unsoaked)	8.97 mg/g	[139]
		Extrusion (Unsoaked; 140°C and 180° C; 18% and 22% moisture)	7.90–8.34 mg/g	
		Raw (pre-soaked)	8.50 mg/g	
		Extrusion (pre-soaked)	7.14–7.60 mg/g	
	Tannins	Raw (Unsoaked)	330 mg/100 g	
		Extrusion (Unsoaked)	236–278 mg/100 g	
		Raw (pre-soaked)	269 mg/100 g	
		Extrusion (pre-soaked)	200–233 mg/100 g	
	Total phenols	Raw (Unsoaked)	460 mg/100 g	
		Extrusion (Unsoaked)	392–430 mg/100 g	
		Raw (pre-soaked)	393 mg/100 g	
		Extrusion (pre-soaked)	343–379 mg/100 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Chickpeas	Phytic acid	Raw (Unsoaked)	8.21 mg/g	[139]
		Extrusion (Unsoaked; 140°C and 180°C; 18% and 22% moisture)	7.33–8.16 mg/g	
		Raw (pre-soaked)	8.00 mg/g	
		Extrusion (pre-soaked; 140°C and 180°C; 18% and 22% moisture)	8.04 mg/g (140°C, 18%); 7.44 mg/g (180°C, 18%); 7.74 mg/g (140°C, 22%); 7.35 mg/g (180°C, 22%).	
	Tannins	Raw (Unsoaked)	260 mg/100 g	
		Extrusion (Unsoaked; 140°C and 180°C; 18% and 22% moisture)	190–245 mg/100 g	
		Raw (pre-soaked)	210 mg/100 g	
		Extrusion (pre-soaked; 140°C and 180°C; 18% and 22% moisture)	214 mg/100 g (180°C, 18%); 210mg/100 g (180°C, 22%); 196 mg/100 g (140°C, 18%); 195 mg/100 g (140°C, 22%).	
	Total phenols	Raw (Unsoaked)	590 mg/100 g	
		Extrusion (Unsoaked)	470–520 mg/100 g	
		Raw (pre-soaked)	550 mg/100 g	
		Extrusion (pre-soaked)	270–380 mg/100 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Kidney beans	Phytic acid	Raw (Unsoaked)	11.03 mg/g	[139]
		Extrusion (Unsoaked; 140°C and 180°C; 18% and 22% moisture)	9.64–10.90 mg/g	
		Raw (pre-soaked)	9.95 mg/g	
		Extrusion (pre-soaked; 140°C and 180°C; 18% and 22% moisture)	10.41 mg/100 g (140°C, 18%), 10.05 mg/100 g (140°C, 22%); 9.77 mg/g (180°C, 18%); 9.53 mg/100 g (180°C, 22%).	
	Tannins	Raw (Unsoaked)	233 mg/100 g	
		Extrusion (Unsoaked)	196–223 mg/100 g	
		Raw (pre-soaked)	229 mg/100 g	
		Extrusion (pre-soaked)	171–190 mg/100 g	
	Total phenols	Raw (Unsoaked)	639 mg/100 g	
		Extrusion (Unsoaked)	539–621 mg/100 g	
		Raw (pre-soaked)	610 mg/100 g	
		Extrusion (pre-soaked)	413–494 mg/100 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Kidney beans	Phytic acid	Raw	15.9 g/kg DM	[129]
		Extrusion	12.6 g/kg DM (21.4% decreased)	
	Condensed tannins	Raw	3.59 g eq cat/kt DM	
		Extrusion	0.58 g eq cat/kt DM (83.8% decreased)	
	Polyphenols	Raw	2.07 g/kg DM	
		Extrusion	1.12 g/kg DM (45.9% decreased)	
	Trypsin inhibitors	Raw	3.10 IU/mg DM	
		Extrusion	0.43 IU/mg DM (86.1% decreased)	
	Chymotrypsin inhibitor	Raw	3.97 IU/mg DM	
		Extrusion	0.00 IU/mg DM (100% decreased)	
	α-Amylase inhibitors	Raw	248 IU/g DM	
		Extrusion	0.00 IU/g DM (100% decreased)	
	Hemagglutinating activity	Raw	74.5 HU/mg DM	
		Extrusion	0.2 HU/mg DM (99.7% decreased)	
Lentil (flour samples)	Total phenolics	Raw	4.68 mg GAE/g	[140]
		Extrusion	5.18 mg GAE/g (increased)	
	Hydroxybenzoic acids	Raw	2.52 mg GAE/g	
		Extrusion	4.40 mg GAE/g (increased)	
	Hydroxycinnamic acids	Raw	9.79 mg FAE/g	
		Extrusion	12.28 mg FAE/g	
	Flavonols	Raw	13.50 mg QE/g	
		Extrusion	5.09 mg QE/g	
Rice-extruded Bean/Carob flours	Anthocyanins and total phenolics	Extrusion	Around 11%–36% increased	[64]
Formulated lentil-nutritional yeast flours	Lectin	Extrusion (140°C; 160°C)	95.0–99.6% decreased	[141]
	α-galactosides	Extrusion (140°C; 160°C)	Increase (up to 85%)	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Germination				
Soybean (Bangladesh soybean-4)	Total folate content	Raw	230.5 μg/100 g FW	[142]
		Germination	815.2 μg/100 g FW	
Soybean (HeiNong48)	Total folate content	Raw	202.9 μg/100 g FW	
		Germination	759.5 μg/100 g FW	
Mung bean (BARI mung-4)	Total folate	Raw	168.9 μg/100 g FW	
		Germination	690.89 μg/100 g FW	
Mung bean (Sulv3)	Total folate	Raw	141.1 μg/100 g FW	
		Germination	633.9 μg/100 g FW	
Beans	Protocatechuic acid	Raw	32.8–41.4 μg/100 g	[143]
		Germination	n.d.	
	HBA	Raw	32.3–36.1 μg/100 g	
		Germination (6 days)	11.5–15.7 μg/100 g	
	Flavonoids	Raw	n.d.	
		Germination (6 days)	quercetin-3-rhamnoside (297–311 μg/100 g), kaempferol-3-rutinoside (305–323 μg/100 g) and kaempferol-3-glucoside (72.7–78.3 μg/100 g)	
Lentil	bound phenolic compounds	Raw	38 mg/100 g	[144]
		Germination (3 days)	5 mg/100 g	
		Germination (24 h)	61.3 mg/100 g	
Lentil	Total phenolic content	Raw	53 mg/kg	[143]
		Germination (5 days)	78 mg/kg	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Mung bean	Vitamin C	Raw	11.69 mg/100 g DW	[145]
		Germination (8 days)	285 mg/100 g DW	
	Total phenilc content	Raw	214.7 mg GA equiv/100 g DW	
		Germination (9 days)	966.4 mg GA equiv/100 g DW	
	Free phenolics	Raw	170.8 mg GA equiv/100 g DW	
		Germination (9 days)	925.4 mg GA equiv/100 g DW	
	Bound phenolic	Raw	43.91 mg GA equiv/100 g DW	
		Germination (1–9 days)	48.26 and 40.96 mg GA equiv/100 g DW (non-significance)	
	Quercetin-3-*O*-glucoside	Raw	0.49 mg/100 g DW	
		Germination (4 days)	5.95 mg/100 g DW	
		Germination (5 days and after)	10.98 mg/100 g DW	
Horse gram	TPC	Raw	46.53 mg GAE/g	[146]
		Germination	52.33 mg GAE/g	
	Oxalate	Raw	3.18 mg/g	
		Germination	1.73 mg/g	
	Phytate	Raw	10.23 mg/g	
		Germination	5.76 mg/g	
	Tannin	Raw	16.18 mg/g	
		Germination	10.28 mg/g	
Faba Bean	Phytic Acid	Germination	75% decreased	[147]
Solara beans	Phytic Acid	Raw	1.33 g/100 g	[148]
		Germination (24 h)	0.97 g/100 g	
		Germination (48 h)	0.88 g/100 g	
		Germination (72 h)	0.76 g/100 g	
Soya beans	Kunitz trypsin inhibitor	Germination (8 days)	Decreased	[149]

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Black bean	Soysaponin Af	Raw	0.65 mg/g	[150]
		Germination (1 day)	0.98 mg/g	
		Germination (2 days)	0.54 mg/g	
		Germination (3 days)	1.45 mg/g	
		Germination (4 days)	7.38 mg/g	
Roasting				
Beans (kidney beans, black-eyed peas, pinto beans, soybeans)	Total phenolics	Raw	100%	[151]
		Roasting (Black-eyed peas)	27%	
		Roasting (Kidney beans)	24%	
		Roasting (Pinto beans)	18%	
Faba beans	phytic acid	Raw	2.62 mg/g	[152]
		Roasting	2.23 mg/g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Faba beans	Total phenolic content	Raw	10.7mg GAE/g DW	[153]
		Roasting (10 min)	8.3 mg GAE/g DW	
		Roasting (30 min)	5.5 mg GAE/g DW	
		Roasting (60 min)	5.2 mg GAE/g DW	
		Roasting (120 min)	6.2 mg GAE/g DW	
	Total flavonoid content	Raw	2.8mg CE/g DW	
		Roasting (10 min)	2.3 mg CE/g DW	
		Roasting (30 min)	1.6 mg CE/g DW	
		Roasting (60 min)	1.8 mg CE/g DW	
		Roasting (120 min)	1.6 mg CE/g DW	
	Total proanthocyanidins	Raw	0.23mg CE/g DW	
		Roasting (10 min)	0.16 mg CE/g DW	
		Roasting (30 min)	0.14 mg CE/g DW	
		Roasting (60 min)	0.13 mg CE/g DW	
		Roasting (120 min)	0.16 mg CE/g DW	
Mangrove legume (*Canavalia cathartica*)	TPC	Raw	1450 mg/100 g d.w.	[154]
		Roasting	1440 mg/100 g d.w.	
Bambara groundnut (*Vigna subterranean*)	Oxalate	Raw	490.6 mg/100 g	[155]
		Roasting	466.2 mg/100 g	
	Tannin	Raw	3.09 moldm−3	
		Roasting	2.56 moldm−3	
	Phytate	Raw	353.9 mg/100 g	
		Roasting	346.9 mg/100 g	
	Saponin	Raw	4.6%	
		Roasting	4.2%	
	Alkaloid	Raw	6.2%	
		Roasting	4.4%	
	Cyanide	Raw	4.13 moldm−3	
		Roasting	3.64 moldm−3	
	Chemotrypsin	Raw	0.4674 g	
		Roasting	0.4090 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Adzuki beans	Phytic Acid	Roasting (600 W, 7 min)	3.50 mg/g	[156]
		Roasting (600 W, 14 min)	2.42 mg/g	
		Roasting (600 W, 21 min)	2.28 mg/g	
	Trypsin inhibitor activity	Roasting (600 W, 7 min)	0.72 mg TI/g	
		Roasting (600 W, 14 min)	0.45 mg TI/g	
		Roasting (600 W, 21 min)	0.17 mg TI/g	
	TPC	Roasting (600 W, 7 min)	6.21mg GAE/g	
		Roasting (600 W, 14 min)	17.12 mg GAE/g	
		Roasting (600 W, 21 min)	25.32 mg GAE/g	
	Saponins	Roasting (600 W, 7 min)	1.56 mg/g	
		Roasting (600 W, 14 min)	1.54 mg/g	
		Roasting (600 W, 21 min)	1.53 mg/g	
Cowpea (Paiyur 1)	Tannin	Raw	760 mg/100 g	[157]
		Roasting	390 mg/100 g	
	Phytic acid	Raw	153.80 mg/100 g	
		Roasting	120.31 mg/100 g	
	Trypsin inhibitor	Raw	2866.85 TIA/100 g	
		Roasting	1140.56 TIA/100 g	
Black gram (VBN(Bg)4)	Tannin	Raw	859.3 mg/100 g	
		Roasting	540 mg/100 g	
	Phytic acid	Raw	674 mg/100 g	
		Roasting	553 mg/100 g	
	Trypsin inhibitor	Raw	2463.25 TIA/g	
		Roasting	1002.45 TIA/g	
Steaming				

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Green bean	Total ascorbic acid	Steaming (115°C, 0 min)	5.33 mg/100 g green bean	[158]
		Steaming (115°C, 10 min)	4.68 mg/100 g green bean	
		Steaming (115°C, 20 min)	5.00 mg/100 g green bean	
		Steaming (115°C, 40 min)	5.11 mg/100 g green bean	
		Steaming (20min, raw)	5.33 mg/100 g green bean	
		Steaming (20min, 100°C)	5.32 mg/100 g green bean	
		Steaming (20min, 115°C)	5.00 mg/100 g green bean	
		Steaming (20min, 121°C)	5.15 mg/100 g green bean	
		Steaming (20min, 115°C)	5.00 mg/100 g green bean	
		Steaming (20min, 121°C)	5.15 mg/100 g green bean	
	Total phenolics	Steaming (115°C, 10 min)	36% decreased	
		Steaming (115°C, 20 min)	32% decreased	
		Steaming (115°C, 30 min)	30% decreased	
	Total flavonoids	Steaming (115°C, 10 min)	60% decreased	
		Steaming (100°C, 120 min)	60% decreased	
Green beans (Purple(*Cv Purple Queen*))	Total phenols	Raw	23.20 mg GAE/100 g FW	[159]
		Steaming	21.68 mg GAE/100 g FW	
Green beans (Green (*Cv Allure*))	Total phenols	Raw	11.87 mg GAE/100 g FW	
		Steaming	8.3 mg GAE/100 g FW	
Green beans (Yellow (*Cv Brittle Wax*))	Total phenols	Raw	7.81 mg GAE/100 g FW	
		Steaming	6.29 mg GAE/100 g FW	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Green pea	Total phenolic content	Conventional steaming, 70 min	25.0% decreased	[76]
		Pressure steaming, 15 psi, 60 min	10.5% decreased	
	Procyanidin content	Conventional steaming, 70 min	8.9% decreased	
		Pressure steaming, 15 psi, 60 min	20.7% decreased	
	Saponin	Conventional steaming, 70 min	15.8% decreased	
		Pressure steaming, 15 psi, 60 min	9.5% decreased	
	Phytic acid	Conventional steaming, 70 min	18.2% decreased	
		Pressure steaming, 15 psi, 60 min	20.7% decreased	
	Catechin	Raw	205.3 mg/g	
		Conventional steaming, 70 min	129.9 mg/g	
		Pressure steaming, 15 psi, 60 min	130.9 mg/g	
	Total flavan-3-ols	Raw	205.3 mg/g	
		Conventional steaming, 70 min	129.9 mg/g	
		Pressure steaming, 15 psi, 60 min	130.9 mg/g	
Yellow pea	Total phenolic content	Conventional steaming, 70 min	25.9% decreased	
		Pressure steaming, 15 psi, 60 min	12.9% decreased	
	Procyanidin content	Conventional steaming, 70 min	8.5% decreased	
		Pressure steaming, 15 psi, 60 min	17.9% decreased	
	Saponin	Conventional steaming, 70 min	5.2% decreased	
		Pressure steaming, 15 psi, 60 min	17.5% decreased	
	Phytic acid	Conventional steaming, 70 min	16.7% decreased	
		Pressure steaming, 15 psi, 60 min	20.6% decreased	
	Catechin	Raw	282.9 mg/g	
		Conventional steaming, 70 min	186.3 mg/g	
		Pressure steaming, 15 psi, 60 min	135.8 mg/g	
	Total flavan-3-ols	Raw	282.9 mg/g	
		Conventional steaming, 70min	186.3 mg/g	
		Pressure steaming, 15 psi, 60 min	135.8 mg/g	
Green pea	TPC	Regular Steaming (70 min)	13.9% decreased	[134]
		Pressure Steaming (5 psi, 70 min)	27.9% decreased	
		Pressure Steaming (15 psi, 60 min)	15.6% decreased	
Chickpea	TPC	Regular Steaming (70 min)	2.8% decreased	
		Pressure Steaming (5 psi, 70 min)	7.6% decreased	
		Pressure Steaming (15 psi, 60 min)	4.3% decreased	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Vigna. racemosa	Phytic acid	Raw	63.15 mg/g	[160]
		Atmospheric steaming	25.87 mg/g (59.03% decreased)	
		Pressure steaming	25.10 mg/g (60.25% decreased)	
	Saponin	Raw	5.15 mg/g	
		Atmospheric steaming	1.48 mg/g (71.26% decreased)	
		Pressure steaming	1.55 mg/g (69.90% decreased)	
	Trypsin inhibitor activity	Raw	9.72mg/g	
		Atmospheric steaming	0.00 mg/g (100% decreased)	
		Pressure steaming	0.00 mg/g (100% decreased)	
Cowpea-based products	Phytic acid	Steaming	7.8–14.0% decreased	[161]
	Tannin	Steaming	19.6–24.7% decreased	
	Trypsin inhibitor activity	Steaming	64.2–72.0% decreased	
Soya beans	Lectins	Raw	7638 µg/g	[162]
		Steaming (102°C, 10 min)	1005 µg/g	
		Steaming (102°C, 20 min)	105 µg/g	
		Steaming (102°C, 40 min)	14 µg/g	
		Steaming (120°C, 2 min)	<0.5 µg/g	
Faba seeds	Total phenolic acid	Control	3.86 mg GAE/g d.w.	[70]
		Steaming (15 min)	3.76 mg GAE/g d.w.	
		Steaming (30 min)	3.67 mg GAE/g d.w.	
		Steaming (45 min)	3.67 mg GAE/g d.w.	
		Steaming (60 min)	3.74 mg GAE/g d.w.	
	Total flavonoid acid	Control	1.00 mg CE/g d.w.	
		Steaming (15 min)	1.20 mg CE/g d.w.	
		Steaming (30 min)	1.05 mg CE/g d.w.	
		Steaming (45 min)	1.18 mg CE/g d.w.	
		Steaming (60 min)	1.12 mg CE/g d.w.	
Autoclaving				
Faba beans	Phytic acid	Raw	399 mg/100g	[147]
		Autoclaving	205 mg/100g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Common beans	Trypsin inhibitors	Unprocessed	1918.64 UI/g	[163]
		Autoclaving (0.5 Kgf cm−2/111 C, 15 min)	1025.23 UI/g	
		Autoclaving (0.5 Kgf cm−2/111 C, 45 min)	977.77 UI/g	
		Autoclaving (1.5 Kgf cm−2/127 C, 15 min)	770.75 UI/g	
		Autoclaving (1.5 Kgf cm−2/127 C, 45 min)	790.43UI/g	
	α-amylase inhibitors	Unprocessed	6512.83 UI/g	
		Autoclaving (0.5 Kgf cm−2/111 C, 15 min)	5809.05 UI/g	
		Autoclaving (0.5 Kgf cm−2/111 C, 45 min)	5534.83 UI/g	
		Autoclaving (1.5 Kgf cm−2/127 C, 15 min)	4337.99 UI/g	
		Autoclaving (1.5 Kgf cm−2/127 C, 45 min)	4002.07UI/g	
Chickpea (Gokce variety from Turkey)	Phytate	Autoclaving (1:2, *w/v*) after 2-h pre-soaked	47% decreased	[164]
Chickpea (CP-98 variety from Pakistan)	Phytate	Autoclaving at 121°C for 10, 20, 40, 60, and 90 min (after 4h pre-soaking)	31–46% decreased	[165]
	Tannin		33–40%	
Bean (*Raba cultivar*)	TPC	Raw	105.8 mg GAE/100 g	[166]
		Autoclaving	78.6 mg GAE/100 g	
Bean (*Warta cultivar*)	TPC	Raw	93.5 mg GAE/100 g	
		Autoclaving	77.1 mg GAE/100 g	
Pea (*Milwa cultivar*)	TPC	Raw	93.4 mg GAE/100 g	
		Autoclaving	80.0 mg GAE/100 g	
Lentil (*Anita cultivar*)	TPC	Raw	782.4 mg GAE/100 g	
		Autoclaving	533.4 mg GAE/100 g	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Canadian cowpea	Tannin	Raw	22.63 mg/g	[130]
		Autoclaving	8.42 mg/g	
	Phytic acid	Raw	0.801 g/100 g	
		Autoclaving	0.280 g/100 g	
	Trypsin inhibitor activity	Raw	2400.91TIU/g	
		Autoclaving	0.00	
Canadian kidney bean	Tannin	Raw	67.09 mg/g	
		Autoclaving	19.54 mg/g	
	Phytic acid	Raw	1.188 g/100 g	
		Autoclaving	0.384 g/100 g	
	Trypsin inhibitor activity	Raw	3583.22TIU/g	
		Autoclaving	0.00	
Canadian pea	Tannin	Raw	30.93 mg/g	
		Autoclaving	2.57 mg/g	
	Phytic acid	Raw	0.815 g/100 g	
		Autoclaving	0.265 g/100 g	
	Trypsin inhibitor activity	Raw	1297.22 TIU/g	
		Autoclaving	0.00	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Faba bean (*Nura*)	TFC	Raw	1.69 mg CE/g DW	[167]
		Autoclaving	0.43 mg CE/g DW	
	Total proanthocyanidins	Raw	0.28mg CE/g DW	
		Autoclaving	0.27mg CE/g DW	
	TPC	Raw	10.9 mg GAE/g DW	
		Autoclaving	1.80 mg GAE/g DW	
Faba bean (*Rossa*)	TFC	Raw	1.72 mg CE/g DW	
		Autoclaving	0.44 mg CE/g DW	
	Total proanthocyanidins	Raw	0.13mg CE/g DW	
		Autoclaving	0.17mg CE/g DW	
	TPC	Raw	11.2 mg GAE/g DW	
		Autoclaving	1.9 mg GAE/g DW	
Chickpea (H-208)	TPC	Raw	846 mg/100 g	[168]
		Autoclaving	638 mg/100 g (25% decreased)	
Chickpea (C-235)	TPC	Raw	835 mg/100 g	
		Autoclaving	642 mg/100 g (23% decreased)	
Black gram (*T*-9)	TPC	Raw	842 mg/100 g	
		Autoclaving	660 mg/100 g (22% decreased)	
Faba bean	Hemagglutinin activity	Raw	3.85 unit/mg	[31]
		Autoclaving	0	
	Trypsin inhibitor	Raw	8.13 unit/mg protein	
		Autoclaving	1.27 unit/mg protein	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Vigna unguiculata subsp. *unguiculata*	Total free phenolics	Raw	1.21 g/100 g	[169]
		Autoclaving	0.35 g/100 g (71% decreased)	
	Tannins	Raw	0.38 g/100 g	
		Autoclaving	0.07 g/100 g (82% decreased)	
	Hydrogen cyanide	Raw	0.22 mg/100 g	
		Autoclaving	0.08 mg/100 g (64% decreased)	
	Phytic Acid	Raw	398.28 mg/100 g	
		Autoclaving	118.40 mg/100 g (70% decreased)	
	Trypsin Inhibitor	Raw	26.48 TIU mg−1 protein	
		Autoclaving	2.21 TIU mg−1 protein (92% decreased)	
Boiling & Cooking				
Common peas	Total phenolic content	Raw	558.2mg GAE/100 g DW	[170]
		Cooking	520.5mg GAE/100 g DW	
	Total flavonoid content	Raw	348.3 mg QAE/100 g DW	
		Cooking	210.1mg QAE/100 g DW	
	Monomeric anthocyanin content	Raw	8.8mg CAE/100 g DW	
		Cooking	4.0mg CAE/100 g DW	
Pigeon pea	Total phenolic content	Raw	201.4mg GAE/100 g DW	
		Cooking	172.4 mg GAE/100 g DW	
	Total flavonoid content	Raw	61.7mg QAE/100 g DW	
		Cooking	46.5 mg QAE/100 g DW	
	Monomeric anthocyanin content	Raw	5.3 mg CAE/100 g DW	
		Cooking	2.2 mg CAE/100 g DW	
Red beans	Total polyphenol	Raw	84.50 mg GAE/100 g DW	[171]
		Cooking	119.31mg GAE/100 g DW	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Black bean	Phenolic acids	Boiling	61% decreased	[172]
Black soybean			62% decreased	
Chickpea			56% decreased	
Lentil			41% decreased	
Pea			37% decreased	
Yellow soybean			61% decreased	
Faba bean	Hemagglutinin activity	Raw	3.85 unit/mg	[31]
		Cooking	0	
	Trypsin inhibitor	Raw	8.13 unit/mg protein	
		Cooking	2.32 unit/mg protein	
Canavalia ensiformis	Hemagglutinin activity	Raw	13531.8 HU/g	[173]
		Cooking (1st stage Cooking)	102.0 HU/g	
		Cooking (2nd stage Cooking)	12.1 HU/g	
		Cooking (3-h cook)	<3.6 HU/g	
Canavalia braziliensis	Hemagglutinin activity	Raw	10204.1 HU/g	
		Cooking (1st stage Cooking)	285.7 HU/g	
		Cooking (2nd stage Cooking)	71.4 HU/g	
		Cooking (3-h cook)	<3.6 HU/g	
Common bean (CNF 0178)	Trypsin inhibitor activity	Raw	119 unit/mg	[174]
		Cooking (60 min)	8.1 unit/mg	
		Cooking (90 min)	7.9 unit/mg	

(*Continued*)

Table 4. (Continued).

Pulse source	Compounds studied	Processing methods	Content of studied compounds	References
Lima beans (*Phaseolus lunatus*)	Trypsin inhibitor activity	Raw	3.4 Tiu/ml	[175]
		Cooking (60 min)	0	
	Phytic acid	Raw	234 mg/100 g	
		Cooking (60 min)	198 mg/100 g	
		Cooking (120 min)	131 mg/100 g	
	Tannins	Raw	0.59 mg/g	
		Cooking (60 min)	0.31 mg/g	
Black beans	TPC	Raw	1.99 mg CE/g	[176]
		Cooking	0.24 mg CE/g	
Red beans	TPC	Raw	6.42 mg CE/g	
		Cooking	0.12 mg CE/g	
White beans	TPC	Raw	0.24 mg CE/g	
		Cooking	0.12 mg CE/g	
Brown beans	TPC	Raw	9.19 mg CE/g	
		Cooking	0.38 mg CE/g	

Abbreviations: n.d.=not detected; TPC=Total phenolic content; TFC=Total flavonoid content; CE=Catechin equivalents. GAE= Gallic acid equivalents; FAE =Ferulic acid equivalents; QE=Quercetin equivalents.grams. Moreover, flavones and flavanones levels in studied lentils were noted to decrease, owing to the leaching and oxidative deterioration.[135].

stability in pulses. Lorenz, et al.[198] have suggested that extrusion processing can successfully retain up to 80% of the vitamin C in the studied pulse sample.[199]

Germination

Germination is usually applied to effectively reduce the anti-nutrient content of grains and pulses and simultaneously alters the food products' nutritional level, biochemical properties, and physical characteristics.[200,201] The enzyme phytase in pulse and other plant seeds is often activated during germination, which destroys phytate and lowers the content of phytic acid in the final products.[202] Different studies demonstrated that germination is a more efficient processing method than thermal processing for eliminating phytic acid in pulses, including chickpeas, peas, and faba beans.[147,203] For instance, in Khalil,[147] the losses of phytic acid were up to 75% in germinated faba beans, significantly higher than in soaked (27%), autoclaved (49%), or cooked (40%) samples.

The TPC, tannin content, and other phenolic compounds can also be significantly influenced during germination processing. For instance, Guo, et al.[145] reported a marked increase in TPC, free phenolics, bound phenolics, and Quercetin-3-*O*-glucoside in smung bean after germination. This might have occurred because, in comparison to raw seeds, germination can lead to the gradual accumulation of soluble phenolics in pulse sprouts and seeds.[204] Moktan and Ojha[146] also reported increased TPC (from 46.53 to 52.33 mg GAE/g) and antioxidant capacities in germinated horse grams. Moreover, in Mamilla and Mishra[205] experiment, germination altered the TPC in chickpea and red lentil samples; while the TPC in kidney beans showed non-influence, which may be due to the reduced water absorption caused by increased polyphenol oxidase activity and a thicker seed coat.

Germination can also affect other antinutritional and certain bioactive substances in pulses. Although not as severe as thermal treatment, germination can considerably diminish enzyme inhibitor activity in general.[206] In addition, the saponin content of pulses may also be influenced within the germination stage. Guajardo-Flores, et al.[150] demonstrated that the concentration of total saponins in sprouts and cotyledons approximately doubled after the 1-day germination; however, the amount of the most abundant soybean saponins in germinated black bean sprouts decreased as germination days went on. Moktan and Ojha[146] also claimed the reduced oxalate (from 3.18 to 1.73 mg/g) in horse grams due to germination. Furthermore, Shohag, et al.[142] reported a remarkably increased total folate content in germinated soybean and mung bean samples. And Mubarak[207] found the mineral content was effectively retained in mung bean seeds with decreased levels of stachyose and raffinose after the germination process.

Roasting

Roasting is a traditional thermal processing method that can suppress the adverse effects of antinutritional factors in pulses. Roasting is effective in removing total phenolic compounds (from 1450 to 1440 mg/100 g d.w.) but less effective than the pressure-cooking method (940 mg/100 g d.w.) in mangrove legume *Canavalia cathartica*, as Seena, et al.[154] reported. Boateng, et al.[151] also found a significant reduction in TPC in studied black eye pea, kidney bean, and pinto bean. However, some reverse results have been reported. Bolek[156] discovered that the roasting process increased TPC and the antioxidant capacity of adzuki beans (*Vigna angularis*). The rise in phenolic levels during the roasting process may be caused by heat-induced changes in the molecule structures of substances related to the corresponding phenolic compounds.

On the other hand, roasting can significantly reduce other antinutrients. As Seena, et al.[154] indicated, roasting effectively diminishes the hemagglutinin activity in raw seeds. In Aremu, et al.[155] study, the oxalate, tannin, phytate, chemotrypsin, and saponin in roasted bambara groundnut, scarlet runner bean, and lima bean exhibited marked reduction individually compared to their raw samples; while the reducing effects through roasting are not pronounced as boiling. In addition, roasted adzuki beans showed a significant decrease in phytic acid content, saponin content, and trypsin inhibitor activity.[156] Similar reducing effects on trypsin inhibitor activity were detected in *Sacha inchi* and *Tamarindus indica* seeds, which may be owing to the denaturation of this inhibitor at an excessive roasting temperature.[208,209]

Moreover, some other bioactive phytochemical compositions will be affected via roasting. For instance, alkaloid and cyanide in the study by Aremu, et al.[155] exhibited a significant reduction after the roasting process in three pulses. Besides, Khattab and Arntfield[130] along with Udensi, et al.[210] noted a significant reduction (24% and 22.63% respectively) in α-galactosides in roasted cowpea and kidney bean seeds. And roasting treatment of faba beans at 120°C for 10 minutes caused a certain extent the elimination of vicine (1–12%) and convicine (3–30%), although not as effective as boiling processing.[211]

Steaming

Steaming is a typical wet thermal processing method applied in food production. Steam processing has several benefits, including a shortened processing time, better retention of antioxidant compounds and activities, and preservation of the appearance and texture of cooked pulses.[134]

Steaming shows significant effects on pulse phenolic compounds. Xu and Chang[134] reported that all the studied pulse samples (green & yellow pea, chickpea, and lentil) exhibited a significant reduction in TPC values after conventional or pressure steaming processing. Simultaneously, the highly retained TPC, DPPH, and ORAC levels in all studied samples were found when compared to the boiling processing. Besides, in another study by Xu and Chang,[76] the conventional and pressure steaming treatments both caused significant ($p < 0.05$) reduction in procyanidin content for all tested pulses. Meanwhile, the two used steaming methods caused reductions in catechin and flavan-3-ols in individual pulse samples. Nevertheless, Duan, et al.[70] indicated that both faba bean seeds and leaves underwent steaming treatments for 30, 45, and 60 minutes with no discernible changes in TFC, which can be attributed to the destruction of heat-sensitive flavonoid compounds, while the comparatively heat-stable components persisted.

In addition, other pulses' antinutritional and bioactive compounds can be affected during steaming processing. Ojo, et al.[160] applied atmospheric steaming and pressure steaming on tested *Vigna racemose* samples and detected a significant decrease in phytic acid, saponin, and tannin. Significantly, the trypsin inhibitor activity diminished by 100% after two steaming methods. As "moin-moin" (a steamed cowpea paste with seasonings) was being produced, the tannins and phytic acid concentrations decreased by 19.6–24.7% and 7.8–14.0%, respectively.[161] As a result of their thermal degradation, the phytate was decreased after heat treatment; this is because phytic acid is naturally thermolabile.[210]

Autoclaving

Autoclaving is one high-pressure cooking approach that employs rapid cycles of high temperature (often operating at 121°C) and pressure (typically operating at 1.8 to 2.0 bar).[212] It is a high-intensity thermal processing method employed in industry to produce canned pulses.[212]

The phenolic compounds in pulses can markedly be influenced by autoclaving treatment. The TPC values in studied beans and peas showed a significant decrease after autoclaving.[166] Jood, et al.[168] reported that autoclaving had the most pronounced effect on phenolic content in chickpea and black gram samples, similar to germination. Significant reductions in total free phenolics (71%) and tannins (82%) were also detected in autoclaved *Vigna unguiculata*, as Kalpanadevi and Mohan[169] reported. Moreover, Siah, et al.[167] found that while TPC and TFC in autoclaved faba bean samples declined significantly, the total proanthocyanidins in *Rossa* faba bean showed a slight increase after autoclaving.

Bioactive substances and antinutritional elements, including tannins, phytic acid, and trypsin inhibitors are reduced or eliminated by autoclaving treatment.[212] This method activates the phytase enzyme and enhances acidity in grains, pulses, and other plant-based diets, causing a reduction in phytic acid after autoclaving.[213] In Khattab and Arntfield[130] study, the autoclaving treatment led to a remarkable decrease in tannin and phytic acid content in six pulses. The phytic acid or phytate in faba bean and chickpeas also exhibited a significant reduction in content after autoclaving.[164] In addition, the enzyme's inhibitory activities may be partially or totally removed by autoclaving due to exposure to excessively high temperature. As Alajaji and El-Adawy[28] reported, autoclaved chickpeas had a substantial decrease in trypsin inhibitor activity. And the trypsin inhibitor activity decreased to zero in autoclaved cowpea, pea, and kidney bean seeds as Khattab and Arntfield[130] studied. Moreover, the α-amylase inhibitor activity in common beans showed a significant decreasing trend under different autoclaving conditions, as Batista, et al.[163] illustrated.

Furthermore, other phytochemicals in pulses can be influenced by autoclaving treatment. Autoclaving caused the highest reduction in oligosaccharides in Khattab and Arntfield[130] research. And the reduction of hydrogen cyanide by up to 64% was reported in *Vigna unguiculata* subsp. *Unguiculata* after autoclaving.[169]

Boiling & cooking

Boiling is a typical cooking method and affects the phytochemicals in pulses. Typically, pulses are boiled in water at 100°C for a short period of time. The boiling approach improves the sensory qualities of pulse seeds, tenderizes the seed, and increases customer acceptability. This treatment also aids in the elimination of heat-sensitive antinutritional compounds. Khalil and Mansour[31] indicated that in faba bean seeds, the boiling treatment removed their hemagglutinins. Carlini and Udedibie[173] also found that jack bean required 3 hours of boiling to become lectin-free and 2 hours to eradicate trypsin inhibitor activity. Over 90% of the trypsin inhibitor activity in common beans can be eliminated by cooking them for 60 minutes at 100°C.[211]

Boiling and cooking can significantly influence the phenolic compounds in pulses. Bressani and Elías[176] noted that heating removes 30–40% of the polyphenols from common beans. Tungmunnithum, et al.[170] reported a significant reduction in TPC, TFC, and monomeric anthocyanin content in peas and pigeon peas. In Aguilera, et al.[79] study, some phenolic compounds, such as the hydroxybenzoic in cannellini bean, as well as catechins, procyanidins, and flavonols in pinto bean, all showed a significant decrease after cooking treatment. Moreover, tannin content was reported to decline significantly by cooking in several common beans and chickpeas in Wang, et al.[48] study.

Other bioactive compounds can be influenced during boiling and cooking. For instance, boiling in water for 10 hours was effective in eliminating vicine and convicine in faba beans, as Abd Allah, et al.[214] reported. Besides, cooking treatment generally leads to a lower tocopherol content in pulses compared to the uncooked controls.[78] Moreover, the marked elevation in the carotenoid range was detected in lentils after cooking, along with the production of 13'-*cis*-lutein and 15-*cis*-lutein.[215]

Effect of pulse storage on phytochemicals

Post-harvest storage of the pulses can alter their chemical composition, including the phytochemicals, and consequently, their nutritional and functional value will be changed.[216]

Pulse storage has significant effects on their phenolic compounds. Granito, et al.[216] stored common beans under three different conditions: 30°C, 11% humidity (C1), 50°C, 11% humidity (C2), and 50°C, 80% humidity (C3). And under C2 and C3 conditions, the TPC content within the first 90 day-storage increased significantly. The deamination of *L*-phenylalanine and *L*-tyrosine, catalysed by the enzyme phenylalanine and tyrosine ammonium lyase, might have caused the rise in TPC. One of phenolic compound derivatives during this process is hydrocinnamic acid, namely ferulic acid.[216] While as for tannin content, it consistently decreased, which may be due to their condensation, migration, and bonding to the cell wall; after 90 days of storage, the TPC started to reduce. However, an inverse result was obtained from Nakitto, et al.[217] study, where the hard-to-cook beans presented greater concentrations of tannin in all studied cultivars compared to the fresh controls, although their

TPC showed a decrease after storage. And there may be a connection between these enhanced tannin compounds and low-molecular-weight non-tannin material, indicating post-harvest biochemical activity within the storage process.

Moreover, some other phytochemical compounds can also be influenced during pulse storage. For example, as Amarowicz and Pegg[218] reported, the total ascorbic acid content in peas stored at 4°C remarkably reduced within 14 days; while after 7 days of storage at 20°C, the ascorbic acid content decreased by 72%. In Bento, et al.[219] study, the lignin content significantly increased in all common bean cultivars during adverse storage.

Bioaccessibility, bioavailability, and digestibility of phytochemicals in pulses

According to the literature, the phenolic compounds' bioaccessibility, i.e., the percentage of a compound liberated from its food matrix in the gastrointestinal tract and subsequently made available for intestinal absorption, determines their bioavailability.[220] Bioaccessibility can be primarily influenced by chemical structure and matrix interactions.[221] According to Nicolás-García, et al.,[177] phenolic compounds are included in cell wall components, in which phenolic acids combine with lignin to produce complexes when the hydroxyl groups on the aromatic ring are bound together. In contrast, insoluble phenolic compounds can interact or bind via covalent bonds with cell wall structural compositions such as cellulose, hemicellulose (including arabinoxylans), lignin, pectin, and structural proteins. Additionally, cellulose and pectin exhibit greater anthocyanin absorption and interaction potential.[177] Other elements that significantly affect the bioaccessibility and bioavailability of phenolic compounds include the substance concentration within the cell wall, changes in the structure of the cell wall, and the position of glycosides within cells.[222]

Most polyphenols found in dietary components are seen as glycosides, esters, or polymers that are commonly difficult to absorb.[223] Before glycosylated phenols are absorbed, the sugar moiety must be eliminated by digestive enzymes (in gastrointestinal mucosa or colonic microflora) or through various food processing methods.[223] The bioaccessibility and bioavailability of phenolic compounds in original pulse seeds are limited (Table 5). According to Sancho, et al.,[226] the bioavailability of total phenols in black bean coat and small red bean coat was only 24% and 49%, respectively, and the tannins in each sample were detected as 6% and 7%, respectively. During *in vitro* digestion, while the free and conjugated phenolic substances are available to be absorbed in human small and large intestines, those covalently bound to indigestible polysaccharides might be absorbed after being released from cell structures via digestive enzymes or microorganisms present in the intestinal lumen.[224] Therefore, the bioaccessibility and bioavailability of relevant phenolic compounds in pulse ingredients will be increased in the digestion process. Chen, et al.[227] noticed a rise in TPC in the intestinal phase compared to the gastric phase during *in vitro* digestion, indicating that the intestinal phase is primarily responsible for releasing phenolics from cooked lentils. Zhang, et al.[225] noted a similar pattern, finding higher total phenolic, flavonoid, and tannin levels during intestinal digestion than during gastric digestion.

The bioaccessibility and bioavailability of phenolic compounds in pulses will generally improve during various food processing approaches as can be observed in Table 5. Lafarga, et al.[221] conducted the *in vitro* gastrointestinal digestion experiment of several pulses, confirming the enhancement impact of cooking treatment on the bioaccessibility of pulse phenolic compounds. Based on the results, cooked soybeans had the highest concentration of bioaccessible polyphenols, followed by faba beans and lentil samples ($p < 0.05$).[221] Hithamani and Srinivasan[228] also found that the roasting process significantly increased the bioaccessible polyphenol content in green gram (11%), and the open pan boiling also had an increasing effect. However, Akillioglu and Karakaya[229] reported that soaking caused a significant reduction (25.61% for hot-water soaking and 38.63% for cold-water soaking) in the total phenols bioavailability of common cooked beans, along with decreased total flavonoid bioavailability, which could be a result of relevant phenolic compounds being released into the soaking water.[229]

Table 5. Bioaccessibility and bioavailability of phenolics in various pulse samples.

			Bioaccessibility/bioavailability of phenolics		
Pulse sample	Phenolic compounds	Processing methods	Gastric phase	Intestinal phase	References
Green lentil	Phenolics	Cooking	21%	50%	[61,221,223–225]
	Flavonoids	Cooking	29%	71%	
Lentils	Total phenolics	Raw	28.61 mg/100 g d.w.	36.44 mg/100 g d.w.	
		Cooking	43.93 mg/100 g d.w.	50.06 mg/100 g d.w.	
Cowpeas	Total phenolics	Raw	19.90 mg/100 g d.w.	22.22 mg/100 g d.w.	
		Cooking	35.26 mg/100 g d.w.	40.02 mg/100 g d.w.	
Faba beans	Total phenolics	Raw	46.51 mg/100 g d.w.	50.16 mg/100 g d.w.	
		Cooking	55.40 mg/100 g d.w.	62.87 mg/100 g d.w.	
Chickpeas	Total phenolics	Raw	19.96 mg/100 g d.w.	22.47 mg/100 g d.w.	
		Cooking	39.52 mg/100 g d.w.	46.65 mg/100 g d.w.	
Soybeans	Total phenolics	Raw	57.29 mg/100 g d.w.	65.57 mg/100 g d.w.	
		Cooking	83.53 mg/100 g d.w.	90.27 mg/100 g d.w.	
Runner beans	Total phenolics	Raw	20.23 mg/100 g d.w.	23.00 mg/100 g d.w.	
		Cooking	34.02 mg/100 g d.w.	40.86 mg/100 g d.w.	
Common beans	Total phenolics	Raw	20.63 mg/100 g d.w.	23.25 mg/100 g d.w.	
		Cooking	28.30 mg/100 g d.w.	33.49 mg/100 g d.w.	
Peas	Total phenolics	Raw	25.35 mg/100 g d.w.	30.39 mg/100 g d.w.	
		Cooking	40.71 mg/100 g d.w.	45.38 mg/100 g d.w.	

Table 6. Biological potential and health impacts of phytochemicals in pulses.

Health impacts	Pulse source	Phytochemicals and characterization	Model	Biological effects	References
Antiobesity potential	Black turtle bean	Phenolic acids (e.g., gallic acid, ferulic acid, sinapic acid)	Biochemical experiments	Lipase inhibitory activity IC_{50}: 0.076 mg/mL	[20]
	Lentil	Phenolic acids (e.g., *trans-p* coumaric acid, *p*-hydroxybenzoic acid)	Biochemical experiments	Lipase Inhibitory activity IC_{50}: 6.26–9.26 mg/mL	[21]
		Flavonoids (e.g., kaempferol, quercetin, catechin glucoside)			
	Adzuki bean	Saponins (Azuki saponin I-VI)	*In vivo*	Enhanced noradrenaline-induced lipolysis of 152.6%	[19]
		Flavonoids (e.g., catechin, quercetin-3-*O*-glucoside)		Enhanced noradrenaline-induced lipolysis of 166.1%, weight loss by 12.2%; Significant decreased serum triglyceride, total cholesterol, low density lipoprotein-cholesterol, and liver lipid.	
Antidiabetes potential	Fermented and non-fermented mung bean	Phenolic compounds	Balb/c mice	200 mg/kg/p.o for 7 days 1000 mg/kg/p.o for 7 days	[234]
	Lupin bean	Phenolic compounds	Biochemical assay	α-amylase inhibition (30–75%) α-glucosidase inhibition (30–70%)	[235]
	Lentil	Phenolic acids (*trans-p* coumaric acid, *p*-hydroxybenzoic acid)	Biochemical assay	α-glucosidase inhibitory activity IC_{50}: 23.08–42.15 mg/mL	[21]
		Flavonoids (e.g., kaempferol-3-*O*-glucoside, catechin glucoside)	Biochemical assay		

(*Continued*)

Table 6. (Continued).

Health impacts	Pulse source	Phytochemicals and characterization	Model	Biological effects	References
Antioxidant potential	Mung bean sprouts, vitexin, isovitexin	Phenolic compounds	Male sprague–dawley rats	Antioxidant and myocardial protective activities	[236]
	Methanolic extract of mung bean hulls	Phenolic compounds	*In vitro*	100 mg/mL	[237]
Antimicrobial potentials	Mung bean sprouts	Phenolic compounds	*Fusarium solani, Fusarium oxysporum, Pythium aphanidermatum*, etc.	Antibacterial and antifungal activity 0.5 mg/mL	[238]
		Phenolic compounds	*Fusarium verticillioides, F. proliferatum, Aspergillus flavus* and *A. parasiticus*	Antifungal activity 0.5 mg/ml	[239]
Anti-inflammatory	Mung bean sprouts	Phenolic compounds	Wistar strain male albino rats	600 mg/kg per day for 13 days	[240]
		Phenolic compounds	Male Wistar rats	100, 500, 1000 µg/mL for 3 weeks	[241]
		Phenolic compounds	*In vitro*	100 mg/mL	[242]

The bioavailability of some other bioactive phytochemical compounds, such as carotenoids, may be influenced by various pulse processing. McInerney, et al.[230]

demonstrated that very little of the lutein as carotenoids in green beans was digested *in vitro* (≤14%); besides, the bioavailability of lutein in green beans was raised by pressure cooking at 600 MPa. Oghbaei and Prakash[231] tested the carotenoids' bioaccessibility in mixed green gram (*Vigna radiata*) and amaranth greens (*Amaranthus caudatus*) and found that when temperature decreased with increased moisture (−17°C, 78.4%), the bioaccessible carotenoids was significantly reduced to 0.18 mg/100 g compared to 0.56 mg/100 g in the control sample (28°C, 3.6%).

Health impacts of pulse consumption

Pulse consumption provides various health benefits. They are highly nutritious, containing roughly twice as much protein as cereals, and providing different essential or non-essential amino acids.[18] Starch is the primary source of easily absorbed carbohydrates in pulse seeds and is present in the highest amounts (22–45%), coupled with oligosaccharides (1.8–18%), and dietary fibre (4.3–25%).[232] Pulse consumption also serves various essential vitamin (e.g., vitamin B) and mineral (e.g., Fe, Ca, Zn, Se, Mg, P, Cu, and K) compounds for humans and animals.[233]

Pulse exerts a strong influence in radical scavenging and detoxifying activities; and demonstrates chemo-preventive benefits due to the high level and efficacy of the phytochemical substances. Table 6 summarizes the biological potential and health impacts of phytochemicals of pulses according to the literature. The phenolic compounds in pulses have been reported to exert various health benefits, which are associated with their antioxidant potential as well as preventive impacts on chronic diseases brought on by free radicals.[243] As the most widely distributed phenolics in pulse seeds, the phenolic acids and flavonoids exhibit significant antioxidant capacities.[244] Also, the pulses' phenolics are confirmed to be related to other favorable properties such as anti-inflammatory and anti-microbial potential.[19] Pulse can help manage obesity by reducing lipid levels when regularly consumed, due to the lipase inhibitory activity by relevant phenolic compounds.[20] They also provide antidiabetic potential due to α-amylase and α-glucosidase inhibition by suitable phenolic compounds.[235] In Hou, et al.[109] review, pulse seed coats' prevention effects on the chronic disease were concluded, including antioxidant, anti-obesity, anti-diabetic, anti-inflammatory, anticancer, and intestinal prebiotic capacities confirmed by a series of *in vitro* and *in vivo* studies. On the other hand, other bioactive and antinutritional compounds in pulses also exhibit health benefits. For instance, the saponin present in pulses shows potential anticarcinogenic and hypocholesterolemic activity.[233] Additionally, phytates in pulses exhibit beneficial health effects, play a valuable antioxidant role, and provide protection from several cancers, coronary heart disease, renal stones, and diabetes mellitus.[245]

Conclusion

Pulses, an inexpensive and sustainable source of nutritional compounds, have been utilized as an essential part of the daily human diet in many countries worldwide. Pulses are a source of nutritional compounds such as proteins, carbohydrates, minerals, and vitamins. In addition, they present several phytochemicals, such as bioactive compounds (e.g., phenolic compounds), and antinutritional compounds. Several listed processing methods, including soaking, germination, and thermal cooking, can influence pulse phytochemicals differently, as it depends on the technological processing and the pulse varieties. Generally, each processing can effectively reduce pulse antinutritional compounds (e.g., phytate, enzyme inhibitors, saponins, lectins, and others), hence improving the bioaccessibility, bioavailability as well as digestibility of nutritional compounds in pulses. Simultaneously, relevant phytochemicals can be positively affected under specific processing treatments. Germination helps increase the level of total phenolics and certain flavonoid compounds.

Moreover, relatively mild thermal processing methods, such as steaming, are more effective in retaining antioxidant compounds and activities in addition to inactivating antinutrients, compared to extrusion and autoclaving. In addition, the consumption of pulses exhibits huge health potential for the human body. The presence of bioactive compounds in pulses such as phenolics, phytosterols, and dietary fibre, are correlated with the prevention of chronic diseases, along with their antioxidant, anti-obesity, anti-diabetic, anti-inflammatory, and anticancer capacities. Thus, it is essential for industries as well as researchers to find more effective methods for improving the bioaccessibility of bioactive constituents in pulses nowadays. The effect of different processing methods on the bioaccessibility of phenolic compounds in various pulses through *in vitro* digestion and colonic fermentation should be further researched, providing supportive information for the commercial utilization of these pulses as functional food ingredients and their pharmaceutical development. Furthermore, epidemiological research and clinical trials can be conducted for more specific information about the role of pulses' bioactive constituents in human health.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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