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UNDERUTILIZED MEXICAN CROP, RUNNER BEAN (PHASEOLUS COCCINEUS): A COMPREHENSIVE REVIEW OF NUTRITIONAL AND FUNCTIONAL IMPLICATIONS.

Cultivo mexicano subutilizado, frijol corredor (Phaseolus coccineus): una revisión integral de sus implicaciones nutricionales y funcionales.

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ABSTRACT

Introduction: The scarlet runner bean (Phaseolus coccineus L.), also known as the runner or ayocote bean, is one of five Phaseolus species domesticated in Mesoamerica. It holds considerable economic importance, ranking third after P. vulgaris and P. lunatus. Despite its relevance, research on its bioactive compounds and potential health benefits still needs to be conducted. **Objective:** This review explores the nutritional composition, anti-nutritional factors, and bioactive compound levels of P. coccineus, emphasizing their implications for consumer health. **Material and method:** A comprehensive literature review, following PRISMA 2020 guidelines, was conducted across electronic databases, identifying 163 relevant studies. After applying inclusion and exclusion criteria, 13 studies were selected for analysis. **Results:** These studies highlighted P. coccineus as a potential source of nutraceutical properties and innovative food products aimed at enhancing nutritional quality. The bioactive compounds, including antioxidants and peptides, suggest benefits in preventing chronic diseases and promoting food security. **Conclusion:** The Ayocote bean (Phaseolus coccineus) is an underutilized legume with notable nutraceutical potential, rich in bioactive compounds that support oxidative stress reduction, immune modulation, and cardiovascular health. Promoting its use benefits food security, rural economies, and germplasm preservation, highlighting its promise for functional foods and dietary supplementation.

Key words: Phaseolus coccineus, nutraceutical properties, incorporating pulses.

RESUMEN

Introducción: El frijol ayocote (Phaseolus coccineus L.), también conocido como frijol escarlata o corredor, es una de las cinco especies de Phaseolus domesticadas en Mesoamérica. Es de importancia económica, ocupando el tercer lugar después de P. vulgaris y P. lunatus. A pesar de su relevancia, la investigación sobre sus compuestos bioactivos y beneficios para la salud es limitada. **Objetivo:** Esta revisión explora la composición nutricional, los factores antinutricionales y los compuestos bioactivos de P. coccineus, con énfasis en sus implicaciones para la salud. **Material y Método:** Se realizó una revisión exhaustiva siguiendo las directrices PRISMA 2020, identificando 163 estudios en bases de datos electrónicas, de los cuales 13 cumplieron los criterios de inclusión para el análisis. **Resultados:** Los estudios destacan a P. coccineus como fuente de propiedades nutracéuticas y productos alimentarios innovadores que mejoran la calidad nutricional. Los compuestos bioactivos, como antioxidantes y péptidos, sugieren beneficios para la prevención de enfermedades crónicas y la seguridad alimentaria. **Conclusión:** Sin embargo, se requiere más investigación para comprender plenamente la composición de compuestos fenólicos, péptidos bioactivos y factores antinutricionales en P. coccineus, promoviendo su uso como alimento funcional y novedoso ingrediente dietético.

Palabras clave: Phaseolus coccineus, propiedades nutraceúticas, incorporación de leguminosas.

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Significance
Beans are considered an important staple food in the Mexican diet. The runner bean is a significant source of nutrients and demonstrates functional potential. Additionally, it possesses characteristics suitable for large-scale cultivation, which could encourage its consumption. Despite this, it is not widely cultivated, and its commercial use remains highly limited. To address these challenges and opportunities, the development of raw materials and new food products derived from the runner bean could contribute to promoting the consumption of this legume, which possesses important functional properties.

Introduction
The genus Phaseolus is widely cultivated and consumed across Africa, India, Mexico, as well as various countries in Central and South America. Presently, it is distributed across all five continents and constitutes a crucial element of many diets. In these regions, it is ingrained in the eating habits of the population, primarily consumed in its whole grain form (Chávez-Mendoza & Sánchez, 2017). The Phaseolus seeds are an essential part of the habitual diet of most of the world's population because it presents a considerable source of protein, complex carbohydrates and fiber. Moreover, they are acknowledged as the second protein source in East and Southeast Africa and rank as the fourth in America, and it comprises various wild and cultivated species, including the common bean (P. vulgaris), lima bean (P. lunatus), tepary bean (P. acutifolius), perennial bean (P. polyanthus), and runner bean (P. coccineus) (Hernández-Delgado et al., 2015). Furthermore, its world production is 27 million tons annually, with a harvest area of more than 34 million hectares (FAOSTAT, 2020).

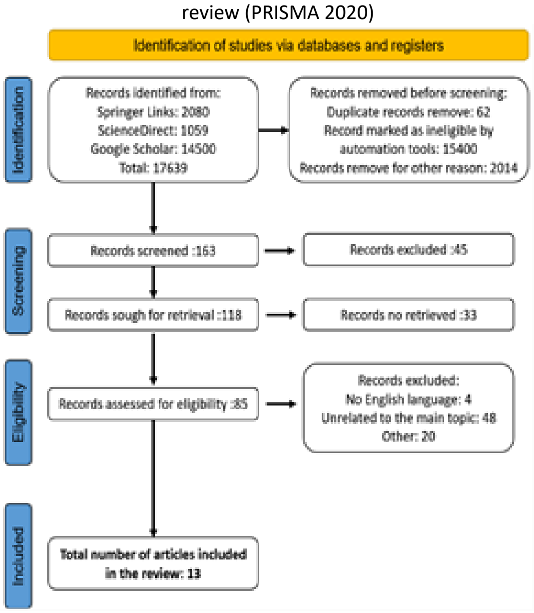
Different types of legumes are cultivated worldwide, exhibiting diverse shapes and sizes. Beans of the genus Phaseolus are pulse crops relevant to human and animal consumption. The common bean (Phaseolus vulgaris) is the most important species worldwide, followed by the lima bean (Phaseolus lunatus), while the runner bean or scarlet runner bean (Phaseolus coccineus), commonly known as ayocote bean, is the third most significant. The common and runner bean crops were domesticated independently within two centers of diversity. This gave rise to two gene pools, Mesoamerican and Andean, with diverse characteristics because of their reproductive and geographic isolation (Sinkovič et al., 2019). Phaseolus coccineus plants are long-day climbing vines, ideal for the summer months and typically exhibit vigorous growth, varying from indeterminate to determinate depending on the variety. While the plants may be damaged by frost at low temperatures, their underground tap roots can survive and regenerate once temperatures increase. Immature pods, green seeds, and mature dry seeds are commonly consumed. The tuberous roots can also be utilized, but caution should be exercised as they may be toxic (Kalloo, 1993).

Phaseolus seeds are a fundamental part of the human diet, though only a few species are widely commercialized, leaving opportunities to explore varieties that offer health benefits beyond essential nutrition. One such species is the runner bean (Phaseolus coccineus), particularly the purple variety, which is noted for its high content of bioactive compounds, including flavonoids (Alvarado-López et al., 2019). These compounds have been associated with potential health benefits, such as lowering cholesterol and improving glucose tolerance, due to their anti-inflammatory and antioxidant activities, thereby enhancing nutritional status (Mullins & Arjmandi, 2021). Despite its promising functional profile, there is limited evidence regarding the concentration of phenolic compounds, bioactive peptides, and anti-nutritional factors in P. coccineus. Given its nutritional and social significance, further research is required to identify bioactive substances that could play a role in preventing chronic degenerative diseases through their nutraceutical properties. This review aims to summarize the current evidence regarding the nutritional composition and the content of bioactive compounds in the runner bean, evaluating its potential health benefits and supporting its use as a functional food and novel dietary ingredient.

Material and method
A comprehensive search was conducted according to the PRISMA 2020 statement (Page et al., 2021) across the electronic databases ScienceDirect, Springer Link, and Google Scholar from inception through 2025. The identification and selection of relevant studies were based on specific keywords, including "benefits," "health," "compounds," "functional," "nutrition," "novel food," and "application." The inclusion criteria consisted of: (1)

studies published in English; (2) relevance to the primary research subject; and (3) availability to digital access. Exclusion criteria encompassed: (1) irrelevance to the main topic; (2) failure to address the research subject; and (3) records such as dissertations, encyclopedias, book chapters, book reviews, mini-reviews, short communications, conference abstracts, conference papers, protocols, reference work entries, theses, or literature reviews (Figure 1). To ensure alignment with the study's focus, all titles and abstracts were reviewed, and those meeting the inclusion criteria were fully analyzed. Additionally, reference lists of retrieved articles were manually screened for further eligible studies.

Figure 1. Flowchart on the stages of including the studies in the review (PRISMA 2020)



Source: Own elaboration

Results

A total of 163 records were initially identified as relevant to the review's objective. Of these, 45 were excluded for not fulfilling the inclusion criteria, and 33 could not be accessed for online retrieval. Furthermore, 72 records were excluded as they either needed to align with the review's primary focus, were not in English, or met the exclusion criteria. The remaining articles were carefully evaluated to ensure they met the abovementioned criteria. Ultimately, 13 articles were included for analysis (Table 1), with 6 addressing nutraceutical properties and 7 focusing on innovative food products incorporating P. coccineus as a novel ingredient to enhance nutritional quality.

Table 1. Compilation of nutraceutical properties and innovative food products enhanced by incorporating Phaseolus coccineus as a novel ingredient.

Study done by	Variety	Sample characteristic	Type of study (tests experiments)	Key findings
(Hasanaklou *et al.*, 2024)	Runner bean (*P. coccineus* L.) variety Bonela	Trypsin inhibitors extraction by different methods	*In vitro* (Trypsin inhibitor activity assay)	Ultrasonic-assisted extraction maximize trypsin inhibitor content and activity
(Teniente-Martínez *et al.*, 2022)	Ayocote bean (*Phaseolus coccineus*) black and purple	Peptides obtained from protein isolates	*In vitro* MDA cells (origin: breast; histopathology: adenocarcinoma of the breast)	Antihypertensive, antioxidant and antiproliferative activities
(Aquino-Bolaños *et al.*, 2021)	Scarlet runner bean (*Phaseolus coccineus*)	Ethanolic extract	*In vitro* (DPPH and FRAP assay)	Antioxidant activity
(Teniente-Martínez *et al.*, 2019)	Ayocote bean (*Phaseolus coccineus*) black and purple	Protein fractions obtained from protein isolates	*In vivo* and *In vitro* Adult male CD1+ mice and SiHa cells (origin: uterus; histopathology: squamous cell carcinoma)	Cytotoxic, genotoxic and anticancer activity
(Pan & Ng, 2015)	Albonanus Bailey (*Phaseolus coccineus* L.)	Isolated a dimeric glucosamine binding lectin	*In vitro* (Breast cancer MCF-7 cells, hepatocellular carcinoma HepG2 cells and nasopharyngeal carcinoma CNE1 cells)	Anti-oxidative, anti-proliferative and cytokine-inducing activities
(Chen *et al.*, 2009)	*Phaseolus coccineus* L. (*P. multiflorus willd*)	Sialic acid-specific lectin isolated	*In vitro* L929 cells and rabbit red blood cells	Antineoplastic and antifungal activities
Innovative food products with improved nutrition incorporating *Phaseolus coccineus* as a novel ingredient				
(Bosmali *et al.*, 2025)	*Phaseolus coccineus*	Raw and roasted beans	Substitution with flours at 20 and 30% (flour basis) in breadmaking *In vitro* (starch digestibility)	Reduced glucose release responses compared to wheat flour bread
(Pedrali *et al.*, 2022)	*Bianco di Spagna (* Phaseolus *coccineus)*	Biscuits made from "Copafam" bean flour	Replacing wheat flour with 25% and 50%	Higher dietary fiber, polyphenol, flavonoid, and anthocyanin content than in a conventional wheat flour biscuit (control sample)
(Espinosa-Ramírez *et al.*, 2022)	*Ayocote bean (Phaseolus coccineus)*	Raw and germinated flour	Substitute 10%, 20%, and 30% of wheat flour in breadmaking	Improves the nutritional properties of bread (protein, minerals, and fiber) and increases limiting amino acid score by 70%
(Mariscal-Moreno *et al.*, 2021)	*Ayocote bean (Phaseolus coccineus)*	Raw flour	Wheat bread. Partial substitute (10%, 20%, and 30%) for wheat flour in breadmaking	Bread containing ayocote beans showed higher values for protein, crude fiber, and ash compared to the control bread
(Corzo-Ríos *et al.*, 2020)	Two varieties of the scarlet runner bean *(Phaseolus coccineus* L.*)*	Raw and cooked	Comparing the effects of thermal treatment on chemical composition and nutritional quality, and identifying the non-nutritional compounds present	Greater concentrations of total phenolic compounds and increased dietary fiber content. After cooking, a 95-100% decrease in non-nutritional compounds
(Sánchez-Villa *et al.*, 2020)	Scarlet runner bean (*Phaseolus coccineus* L.)	Isolated proteins	Fortified masa with 5% and 10% of proteins isolated from scarlet runner bean	Increased protein content by 20% and 37% in comparison with maize tortilla, without modifying the rheological and textural characteristics of the masa and tortilla
(ShuMei *et al.*, 2019)	*Phaseolus coccineus*	Flavonoid extract	Effect of commonly used preservatives *In vitro* (DPPH assay)	Food additives (benzoic acid, sorbic acid and sodium chloride) enhanced the antioxidant activity of flavonoids

Source: Own elaboration

__Agronomic significance of Phaseolus coccineus__

Pulses are a rich source of protein, complex carbohydrates, fiber, vitamins, minerals, and phytochemicals. Due to their high lysine and folate levels, many people worldwide rely on pulses alongside cereals as a primary source of protein. Combining pulses with cereals in composite flour enhances their nutritional value. Notably, pulses and cereal grains share comparable levels of total carbohydrates, fats, niacin, riboflavin, thiamine, and pyridoxine.

Globally, there are around 150 recognized bean species. In Mexico exclusively, there are roughly 65 varieties, with 52 falling under the genus Phaseolus, and 31 species are native to the region (Romero-Arenas et al., 2013). The Phaseolus genus is a significant crop because of its high protein content ranging from 20 to 50% and carbohydrate content ranging from 50 to 65%. Among legumes, Phaseolus coccineus holds particular significance because it can be grown without fertilization, thrives in low temperatures, and withstands water stress. The wild forms of the runner bean (P. coccineus) can be found across the area stretching from Chihuahua in Mexico to Panama. Limited archaeological evidence also suggests that this region served as the original center of origin for P. coccineus. Additionally, all plant parts, including flowers, seeds, pods, and foliage, are usable (González-Cruz et al., 2022). The runner bean is a perennial species that can live up to 10 years, although outside of Central America and Mexico, it is grown annually since it cannot survive frost. It is native to Mexico, Guatemala, and Honduras, and the wild forms are probably not all ancestral. In Mexico and Central America, the most remarkable diversity of P. vulgaris and P. coccineus is conserved as part of traditional cultivation, backyard, and forest systems (Rodriguez et al., 2013).

Nutritional composition

Regarding nutrition, pulses play a crucial role as a significant protein source, even though they may lack sufficient sulfur-containing amino acids and tryptophan. However, pulses contain higher lysine, arginine, glutamic acid, and aspartic acid than cereal grains. Phaseolus coccineus beans predominantly contain carbohydrates and proteins, positioning them as a well-known protein source in developing nations. Additionally, they are rich in dietary fiber, and contain modest amounts of lipids (Table 2). In addition to their well-established nutritional advantages, studies have linked the consumption of pulses to potential protective or therapeutic effects on chronic health conditions, including cardiovascular diseases, diabetes, cancer, overweight and obesity (Ansari et al., 2023; Marinangeli & Jones, 2011).

Table 2. Nutritional composition of dry and raw seeds by *Phaseolus* species

Composition (g/100g)	***Phaseolus* species**		
	P. coccineus	*P. lunatus*	*P. vulgaris*
Moisture	11.2	9.62	10.16
Ashes	4.27	3.48	3.78
Lipids	1.87	1.6	2.22
Protein	17.28	19.68	20.48
Carbohydrates	65.39	65.62	62.57
Fiber	4.18	5.21	5.02

Adapted from: Alcázar-Valle *et al.* (2021).

Protein levels and amino acid composition vary due to factors such as variety, germination, environmental conditions, and fertilizer application. Pulses have protein levels nearly double those found in cereals. These pulse proteins are divided into two primary fractions: albumin and globulin. The predominant storage proteins in pulse seeds are globulins, making up 35–72% of the total protein, while albumins constitute the remaining protein fraction (Shevkani et al., 2019). Globulin proteins contain higher levels of glutamine, aspartic acid, arginine, and lysine. Conversely, albumins typically play a physiological role in smaller quantities than globulins, comprising only 15–25% of the total seed protein (Luna-Vital et al., 2015). Albumins contain elevated cystine, methionine, and lysine levels compared to the globulin fractions. Globulins possess a densely packed, rigid structure attributed to the presence of disulfide bonds and hydrophobic interactions. Among the four primary protein classes in pulses, albumins stand out for their ability to dissolve in water (Singh, 2017).

Bioactive compounds

Bioactive compounds in plants are diverse; their presence depends on environmental conditions. Most of them are generated through the secondary metabolism of plants, and their function is mainly as a reserve, defense or interaction with other plants, microorganisms and insects. The synthesis of these compounds is influenced by geographic location, climatic, genetic factors, and interaction with other species. Therefore, it is essential to maintain biodiversity in crops to ensure permanent access to them. These compounds differ in chemical nature; they have different molecular weights, polarity, solubility, bioavailability, metabolic pathways, and excretion. This will affect the distribution and concentrations of each compound at the target sites (Yeshi et al., 2022).

Phenolic compounds of pulses play a role in the overall antioxidant effects, counteracting free radicals, binding to metal catalysts, triggering antioxidant enzyme activity, and hindering oxidases. The seed coat and cotyledons in Phaseolus seeds exhibit distinct polyphenol compositions, flavonoid levels, and antioxidant activities (Table 3). Notably, the seed coat displays a higher average content of these compounds than the cotyledons. As a result, there is growing attention on utilizing the seed coat as a valuable dietary supplement and for applications within the processed food sector (Capistrán-Carabarin et al., 2019). Currently, scientific evidence exists regarding the advantageous effects on health derived from Phaseolus bean consumption. For instance, certain organic acids act as surfactants for other molecules, while polyphenols can enhance saponin's water solubility. In turn, this augmentation facilitates the transmembrane conveyance of therapeutic molecules (Zhao et al., 2020). Flavonoids and saponins contained in black beans (Phaseolus vulgaris) may diminish cholesterol absorption by impeding the micellar solubility of cholesterol (Chávez-Santoscoy et al., 2013). Conversely, b-carotene heightens the bioavailability of lycopene within human plasma, and quercetin-3-glucoside curtails the absorption of anthocyanins. Consequently, it is advisable to combine the consumption of pulses and vegetables to support synergistic effects that could potentially amplify beneficial attributes. However, it is worth noting that antagonistic interactions could also emerge (Chávez-Santoscoy et al., 2013).

Table 3. Content of phenols, flavonoids, anthocyanins and in vitro antioxidant activity of dry and raw seeds of Phaseolus species

	Phaseolus species	
	P. coccineus	*P. vulgaris*
Seed Coat		
Total Polyphenols[1]	152.4	81.7
Flavonoids[2]	22	10.6
Anthocyanins[3]	0.15	5.12
Antioxidant activity[4]	1169.4	874.2
Cotyledons		
Total Polyphenols[1]	2.41	1.86
Flavonoids[2]	0.3	0.3
Antioxidant activity[4]	8.11	7.41

[1]mg gallic acid equivalents per gram of dry sample; [2]mg catechin equivalents per gram of dry sample; [3]mg of cyanidin-3-glucoside per gram of dry sample; [4] micromoles of Trolox equivalents per gram of dry sample. Adapted from: Capistrán-Carabarin *et al.* (2019).

The coloration of bean seeds arises from the presence and concentration of various compounds such as flavonols (predominantly kaempferol and quercetin), glycosides, anthocyanins, condensed tannins (proanthocyanidins), and phenolic acids (including ferulic, synaptic, chlorogenic, and hydroxycinnamic acids). Notably, the highest proportions of these constituents are observed in beans with purple, black, and brown hues (Alcázar-Valle et al., 2020). Alvarado-López et al., (2019) evaluated the total phenolic content in four runner bean seeds varieties. They significantly exhibited variations across the different cultivars, with the decreasing order being purple, followed by black, brown and finally white (Table 4). Previous comparative analyses on diverse runner bean types have generally shown that white beans tend to have lower total phenolic content compared to certain colored beans. Discrepancies in total phenolic content among studies of beans can be attributed to factors such as genetics, farming practices, harvest maturity, storage conditions, and the solvents employed during extraction (Orak et al., 2016).

Table 4. Total phenolic content, total flavonoids and total anthocyanins for four varieties of *Phaseolus coccineus*

	Variety			
	Purple	Black	Brown	White
Total phenolics[1] (mgGAE/kg)	2075.91	1732.24	1561.25	1292.24
Total flavonoids[2] (mgQE/kg)	1612.96	1501.3	1248.75	1084.51
Total anthocyanins[3] (mgCGE/kg)	1193.27	1082.21	278.92	2.2

[1]Expressed as milligram of gallic acid equivalent/kg (mg GAE/kg);
[2]expressed as milligram of quercetin equivalent/kg (mgQE/kg);
[3]expressed as mg of cyanidin-3 glucoside equivalents/kg (mg CGE/kg).
Adapted from: Alvarado-López *et al*., (2019).

The runner bean is a rich source of vegetable protein. It can be used to supplement the deficiency of different cereals, due to its content of essential amino acids (lysine, arginine, glutamic acid, and aspartic acidamides), fiber, vitamins and minerals such as iron, potassium, magnesium and zinc, among others. It is even considered as one of the primary sources of phenolic acids (hydroxybenzoic and hydroxycinnamic acids), flavonoids (flavonols, flavones, dihydroflavonols, flavanones, isoflavones and isoflavonones), lignans and other polar compounds with possible health benefits such as slowing the development of cancerous tumors and contribute antibacterial, antiviral, antispasmodic and anti-inflammatory properties (Aquino-Bolaños et al., 2021).

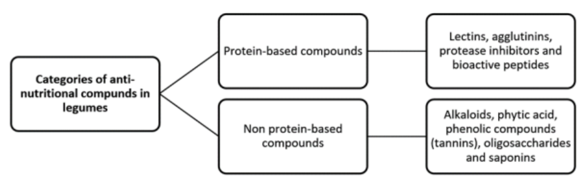
The anticancer activity of beans is mainly related to the presence of high amounts of resistant starch, soluble and insoluble dietary fiber, and phenolic compounds, which suggests that their regular consumption may reduce the risk of breast, colon, and of prostate. Likewise, it has been reported that due to its high fiber content it could help control diabetes by reducing the generation of insulin and glucose levels that enter the bloodstream. In addition, patients who have non-insulin-dependent diabetes can prevent the need for insulin by consuming beans in their regular diet (Jaiswal, 2020).

It has been shown that phenolic components have nutraceutical potential in some common bean species (P. vulgaris) and varieties of P. coccineus and P. lunatus. In addition, there is evidence that native bean species are essential because they contain critical nutritional components for food security and supplementation (e.g., predominant free amino acid content in beans, arginine, aspartic acid, asparagine, glutamic acid, and leucine). These, in addition to playing a key role in structural and physiological functions, are important metabolite precursors, and can also act as antioxidants, which could help reduce oxidative stress, such as tryptophan, phenylalanine, isoleucine or proline (Alcázar-Valle et al., 2021).

<u>Anti-nutritional factors</u>

Anti-nutritional factors refer to compounds commonly found in food items that can harm to humans or interfere with nutrient absorption in the body. These factors exist in various foods in different quantities, depending on the type of food. Many plants and vegetables contain anti-nutrients such as oxalate and phytate and toxic substances like cyanide, nitrate and phenols (Figure 2). These anti-nutrients can negatively impact the absorption of essential nutrients and micronutrients in the body. Nevertheless, some anti-nutrients may have beneficial health effects when present in small amounts (Thakur et al., 2019).

Figure 2. The anti-nutritional factors can be categorized into two primary groups.



Source: Own elaboration

While pulses have a valuable nutritional content, specific individuals decline their consumption due to anti-nutritional elements. Major anti-nutritional factors include phytic acid, lectins, enzyme inhibitors (trypsin, chymotrypsin and amylase), saponins, oligosaccharides, and tannins. For an extended period, these substances have been recognized for their negative physiological impacts on nutrition and health. At certain levels of concentration, they have the potential to impair the digestibility of proteins and carbohydrates and can even turn toxic at significantly elevated concentration. The effects of consuming these substances can be either beneficial or detrimental, contingent upon the quantity ingested. Some of these compounds have exhibited pharmacological effects in studies involving both cell cultures and animal experiments (Boye et al., 2010; Lacaille-Dubois & Melzig, 2016). Several advantageous attributes associated with anti-nutritional substances include properties like chemoprevention, inhibition of cell growth, prevention of mutations, antioxidation, cholesterol reduction, blood sugar regulation, blood pressure control, and prevention of blood clotting. These substances are collectively referred to as bioactive compounds and are known to mitigate the risk of various diseases, including chronic conditions like cardiovascular disorders (Sánchez-Arteaga et al., 2015; Singh et al., 2017).

Trypsin inhibitors, phytates, and α-galacto-oligosaccharides can reduce nutrient bioavailability and cause digestive issues. Trypsin inhibitors block the enzyme trypsin, preventing protein breakdown and amino acid absorption, while phytates chelate essential minerals like zinc, iron, calcium, and magnesium, reducing their absorption. α-Galacto-oligosaccharides are not broken down in the human gut due to the absence of the enzyme α-galactosidase, leading to gut microbiota ferment, which produces gases and causes bloating and flatulence. Removing these components improves the nutritional quality of beans (Njoumi et al., 2019). However, earlier research has revealed a positive correlation between lectins originating from the genus Phaseolus and antioxidant activity, as demonstrated by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay (Alcázar-Valle et al., 2020). Hence, inferring a link between lectins and antioxidant functionality is plausible, which might contribute to mitigating certain inflammation-associated disorders. This suggests a high potential to be used for these lectins to serve as valuable constituents for nutraceutical preparations, given their chemical composition and the potential they hold for fostering biological activities that could be harnessed in product development.

From an anti-nutritional perspective, the insufficient protein digestibility in Phaseolus beans poses a significant nutritional challenge. This fact is frequently linked to trypsin inhibitors, which lower protein effectiveness, decrease food assimilation, and may trigger occupational allergies (Alcázar-Valle et al., 2020). Studies have shown that Phaseolus proteins are not easily broken down (hydrolyzed), which may contribute to their allergenic potential. Processing techniques can alter or denature certain proteins responsible for causing allergic reactions. Additionally, when heat and enzymatic hydrolysis are combined to produce protein hydrolysates, the allergenic potential of the protein is reduced. Nevertheless, the safety of these hydrolysates depends on the extent of hydrolysis and the presence of allergenic fragments within the protein hydrolysate (Mojica et al., 2017).

Lectins

Initial research on lectins derived from different types of runner beans revealed that the lectin found in Phaseolus coccineus specifically binds to N-acetyl-D-galactosamine (Nowaková & Kocourek, 1974). Subsequent investigations in 1978 uncovered that the lectin extracted from runner beans is structured as a tetramer consisting of four similar subunits, each with a weight of around 30 kDa. This lectin contains 20% glucosamine and 8% sugar, and its biological function depends on the presence of Ca+2 and Mg+2 ions. N-acetylgalactosamine, conalbumin, and ovalbumin block it. Moreover, it induces the agglutination of erythrocytes without showing any specific binding to antigens and does not stimulate the proliferation of human peripheral lymphocytes (Ochoa & Kristiansen, 1978).

Numerous studies have indicated that lectins' structural and biological attributes are influenced by the variety of the plant and its cultivation location. Hemagglutination activity appears to be affected by the metallic ions found in the lectin and other factors such as species, variety, and cultivation locations. For instance, in lectins extracted from Phaseolus coccineus grown in China, the presence or absence of metallic ions does not affect hemagglutination activity, whereas in lectins extracted from Phaseolus coccineus originating from Oaxaca, there is a correlation between the presence of metallic ions and hemagglutination activity (Chen et al., 2009; Feria et al., 1996).

Strategies for reduction anti-nutritional compounds

Anti-nutritional factors are chemical compounds produced in natural food and/or feedstuffs through the normal metabolism of species and various mechanisms that have effects that oppose optimal nutrition. Eliminating or minimizing anti-nutritional factors is crucial to enhancing the nutritional value and efficient utilization of legume grains by the population. Therefore, it is imperative to develop processing techniques to ensure their optimal utilization.

The anti-nutritional compounds found in pulses typically diminish their palatability and hinder protein digestibility and mineral bioavailability, consequently limiting their biological value and acceptance in the diet. Therefore, it is essential to process pulses adequately before consumption. Most of these compounds are concentrated in the seed coat and heat-sensitive. Various methods can significantly reduce their levels, including milling, cooking, germination, fermentation and heat processing (Salim et al., 2023). These techniques not only enhance nutrient bioavailability by deactivating anti-nutritional compounds but also improve pulses flavor and overall acceptability. Selecting the appropriate methods for removing or reducing these compounds necessitates understanding their chemical structure, distribution within seed fractions, biological effects, heat sensitivity, and water solubility. Typical methods employed to reduce or eliminate anti-nutritional compounds in pulses include heating, extrusion cooking, milling, dehulling, soaking, sprouting, fermentation, and cooking (Kumar et al., 2022).

While the effects of conventional processing methods on the levels of anti-nutritional factors (like phytate, protein inhibitors, phenolics, tannins, lectins, saponins, among others) have been extensively studied (Patterson et al., 2017), there is a need for novel methods to eliminate these factors. Despite pulses being used in various indigenous products, their functional attributes and potential health benefits have not been fully explored (N. Singh, 2017).

<u>Phaseolus coccineus a source of biologically active peptides</u>

New scientific findings propose that food proteins not only function as essential nutrients but also have the ability to regulate the body's physiological processes. Since the initial publication of the definition of bioactive peptides, there has been ongoing progress in enhancing understanding of these molecules. Research on peptides derived from food has continuously advanced since 1995 when defined bioactive peptides as inactive fragments within protein sequences that exhibit their bioactivity after enzymatic release and interaction with the appropriate receptors in the body. The bioactivity of these peptides encompasses the regulation of various bodily functions, such as antioxidative, antibacterial, immunomodulating, and antithrombotic properties, the reduction of blood pressure, the reduction of blood glucose levels, and cholesterol and displaying, mineral binding functions among others (S. Li et al., 2019). The main control of these physiological functions is carried out by certain peptides that are encoded within the original protein sequences.

Multiple studies suggest that the protein and peptides found in P. coccineus possess significant nutraceutical potential due to their antioxidant, anticancer, antifungal, and antibacterial properties. Phaseolus plants are known to synthesize a variety of antifungal proteins and peptides, making them a focal point of research due to the abundance of biologically active compounds they produce (González-Cruz et al., 2022). These antifungal proteins and peptides have been isolated from various leguminous species. Ngai & Ng, (2005), isolated and purified an antifungal protein with an N-terminal sequence from small scarlet runner beans (P. coccineus) seeds, appoint as phaseococcin. This protein exhibited a molecular mass of 5422 Da determined by mass spectrometry, displays a wide range of functions, including antimicrobial, antiproliferative, and inhibition activities, which resembles a defensin. It inhibits the growth of mycelium in various fungi, as well as the proliferation of several Bacillus species and leukemia cell lines HL60 and L1210. Additionally, it suppresses the activity of HIV-1 reverse transcriptase.

The Phaseolus genus contains significant amounts of lectins, which are carbohydrate-binding proteins of non-immune origin commonly found in legumes. Moreover, they exhibit various significant biological activities, including antineoplastic, immunomodulatory, and antifungal properties. A sialic acid-specific lectin obtained from Phaseolus coccineus seeds was isolated and analyzed by Chen et al., (2009). This lectin, a 56 kDa dimer (comprising subunits weighing 29831 Da each), is a non-metalloprotein. Its N-terminal sequence, consisting of 23 amino acids, exhibited notable antifungal activity against certain plant pathogenic fungi (C. albicans, P. italicum), and inhibited the growth of H. maydis, Rhizoctonia solani, G.

sanbinetti, and S. sclerotiorum. Additionally, experiments assessing cytotoxicity showed that the lectin exhibited significant toxicity towards L929 cells, inducing apoptosis in a dose-dependent manner.

The runner bean (Phaseolus coccineus) shows potential for nutraceutical applications due to its high protein content (around 30%). Teniente-Martínez et al., (2019) investigated the genotoxic and cytotoxic effects of protein isolates and peptides from black and purple runner bean varieties. Using a simulated gastrointestinal digestion process with pancreatin and trypsin, they evaluated the anticancer activity of protein fractions. Results indicated that molecular mass influences their effects on cancer cells, with a synergistic increase in cytotoxicity when combined with daunorubicin. Protein isolates from both varieties also showed moderate genotoxic effects and inhibitory effects against SiHa cancer cells.

On the other hand, Teniente-Martínez et al., (2022) were investigated to establish a potential correlation between the antihypertensive, antioxidant, and anticancer activities against MDA breast cancer cells of peptides extracted from two different runner bean types: black and purple varieties. They aimed to identify potentially beneficial peptides derived from the protein isolate of runner beans. They have subjected the isolate to a simulated gastrointestinal digestion process, mimicking the natural breakdown during digestion. This simulated process utilized proteinases sourced from animal tissues, namely pancreatin and trypsin obtaining peptides similar to those generated through physiological digestion. It was observed that all peptides demonstrated antihypertensive effects. There was a notable increase in antioxidant activity, with the peptides sourced from the purple bean hydrolysate showing an average 1.7 times higher activity compared to those from the black bean hydrolysate. Moreover, peptides obtained from both purple and black bean hydrolysates exhibited a certain degree of inhibition on MDA cell proliferation. These peptides from both types of bean hydrolysates display suitable antihypertensive, antioxidant, and antiproliferative capabilities. However, functional attributes and biological effects of bioactive peptides are influenced by factors such as the type of amino acids, their sequence, and the molecular weight of the peptides (Peighambardoust et al., 2021).

Innovative food products

Pulses contain various polyphenolic compounds, including flavonoids, tannins, anthocyanins, and phenolic acids like p-coumaric, ferulic, and cinnamic acid. While typically consumed as dry seeds, pulses can also be eaten as green pods or used as flour. Pulses flour enhances the nutritional value of food by increasing protein and fiber content and offering functional properties like solubility, gelling, and emulsification, which improve food texture (Schmidt & Oliveira, 2023). Studies show that incorporating pulses flour and bran into snacks enhances sensory qualities such as flavor and texture. Additionally, pulses can partially or fully replace cereals in extruded snack production, a growing market for healthy, minimally processed foods (King et al., 2024).

Previous research has investigated the incorporation of runner bean flour (10-20%) into bread formulations. Findings revealed that bread made with this substitution showed increased mineral, fiber, and nutrient content without negatively impacting digestibility or sensory properties when the addition remained below 20% (Mariscal-Moreno et al., 2021). Similarly, adding isolated proteins from runner beans enhanced the nutritional quality of nixtamalized corn tortillas without compromising rheological, textural, or sensory attributes (Sánchez-Villa et al., 2020). Additionally, α-galactosidase, isolated from runner beans, demonstrated high activity and potential industrial applications, such as improving sucrose crystallization in beet sugar syrups and enhancing the nutritional value of soy beverages by hydrolyzing raffinose and other oligosaccharides (Du et al., 2013).

The runner bean can be utilized to enhance the nutritional profile of baked products. Espinosa-Ramírez et al., (2022) demonstrated that incorporating runner bean flour into wheat flour bread at concentrations of 10%, 20%, and 30% increased fiber, minerals, and protein content compared to bread made solely with wheat flour. Protein quality, measured by the limiting amino acid score, improved by up to 70%, thanks to the essential amino acids present in the bean flour. However, lower substitution levels are recommended to maintain dough stability and sensory attributes such as color, flavor, and texture.

Pedrali et al., (2022), have explored the nutritional and phytochemical attributes of other widely available and commercially popular bean varieties such as Borlotto and Cannellino (P. vulgaris) and Bianco di Spagna (P. coccineus). Moreover, in order to determine the potential of "Copafam" for creating innovative and distinctive products, the effects of incorporating bean flour into a prototype food product (biscuits) on sensory attributes and consumer satisfaction were examined. They found that "Copafam" bean flour biscuits had elevated levels of dietary fiber, secondary metabolites like polyphenols and anthocyanins, and displayed substantial flavonoid content, leading to notable antioxidant properties. These biscuits were characterized by a darker hue and a crispy texture and were well-received by consumers. This study shows an initial exploration, paving the way for further research into alternative applications of bean flour with the goal of establishing it as a valuable resource in the innovative food industry (Rațu et al., 2023).

Phaseolus coccineus bean flour is regarded as a substitute ingredient suitable for specific dietary needs due to its elevated protein content (Corzo-Ríos et al., 2020). Göksel Saraç et al., (2022), evaluated the utilization of scarlet runner bean (Phaseolus coccineus) flour with high protein content to produce a protein-rich cake suitable for vegan consumers. They aimed to determine the properties of the resulting product and analyze consumer preferences. Five different vegan cakes were prepared by incorporating various concentrations of scarlet runner bean flour into wheat flour without any animal products. Analyses were conducted on the baking properties, physicochemical characteristics, biochemical composition, texture, and sensory attributes of the vegan cakes. Increasing the proportion of scarlet runner bean flour resulted in higher levels of protein content, total phenolic compounds, and antioxidant properties observed in the cakes. Furthermore, including scarlet runner bean flour led to improvements in the cake formulation's technological, textural and sensory aspects.

The incorporation of legumes into new food options and the development of formulations, such as extruded snack products containing pulse flour, are appealing food options and are well accepted (Schmidt & Oliveira, 2023). The evaluation of numerous extruded snack formulations made from various pulses (green pea and chickpea) has been conducted (Proserpio et al., 2020). These products, incorporating legume seeds, offer a rich source of fiber and serve as a valuable alternative to meet the increasing global demand for high-fiber and gluten-free products. From a sustainability perspective, using legumes can help reduce the environmental impact of this food category. Furthermore, they could serve as a sustainable source of fiber and high-quality proteins, providing a valuable alternative to products available in the market (Proserpio et al., 2020; Saint-Eve et al., 2019).

Conclusions

The Ayocote bean (Phaseolus coccineus) emerges as a valuable yet underexploited legume with considerable nutraceutical potential. This legume is a rich source of bioactive compounds, including phenolic components and antioxidant peptides, which play critical roles in mitigating oxidative stress, modulating immune responses, and promoting cardiovascular and metabolic health. Considering its robust phytochemical composition and functional attributes, the Ayocote bean holds significant promise in addressing food security, dietary supplementation, and the development of functional foods with health-promoting benefits. This would help encourage both the cultivation and consumption of Ayocote beans, providing direct benefits to the food and economic security of rural communities, while also safeguarding unexplored germplasm with potential health advantages and preserving the local gene pool.

Pulses provide substantial nutritional, environmental, and health benefits, yet further research is required to optimize their application in innovative food products. One of the main obstacles to their broader adoption is the limited awareness of their diverse properties, particularly in local varieties such as the runner bean (Phaseolus coccineus). Challenges such as low protein digestibility and the presence of anti-nutritional factors emphasize the need for advanced processing methods to enhance their utility. Although local varieties like Phaseolus coccineus possess notable nutritional advantages, more extensive research is essential to investigate and confirm their nutraceutical potential. This includes integrating them into novel food products, exploring their mechanisms of action, elucidating the relationship between their bioactive compounds and molecular properties, and assessing their overall effects on human health. Given their minimal environmental impact, pulses are uniquely positioned to contribute significantly to sustainable food systems, aligning with global recommendations advocating for their increased utilization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Alcázar-Valle, M., García-Morales, S., Mojica, L., Morales-Hernández, N., Sánchez-Osorio, E., Flores-López, L., Enríquez-Vara, J. N., & Lugo-Cervantes, E. (2021). Nutritional, Antinutritional Compounds and Nutraceutical Significance of Native Bean Species (*Phaseolus* spp.) of Mexican Cultivars. *Agriculture*, *11*(11), 1031. https://doi.org/10.3390/agriculture11111031

Alcázar-Valle, M., Lugo-Cervantes, E., Mojica, L., Morales-Hernández, N., Reyes-Ramírez, H., Enríquez-Vara, J. N., & García-Morales, S. (2020). Bioactive Compounds, Antioxidant Activity, and Antinutritional Content of Legumes: A Comparison between Four *Phaseolus* Species. *Molecules*, *25*(15), 3528. https://doi.org/10.3390/molecules25153528

Alvarado-López, A. N., Gómez-Oliván, L. M., Heredia, J. B., Baeza-Jiménez, R., Garcia-Galindo, H. S., & Lopez-Martinez, L. X. (2019). Nutritional and bioactive characteristics of Ayocote bean (*Phaseolus coccienus* L.): An underutilized legume harvested in Mexico. *CyTA - Journal of Food*, *17*(1), Art. 1. https://doi.org/10.1080/19476337.2019.1571530

Ansari, P., Samia, J. F., Khan, J. T., Rafi, M. R., Rahman, Md. S., Rahman, A. B., Abdel-Wahab, Y. H. A., & Seidel, V. (2023). Protective Effects of Medicinal Plant-Based Foods against Diabetes: A Review on Pharmacology, Phytochemistry, and Molecular Mechanisms. *Nutrients*, *15*(14), 3266. https://doi.org/10.3390/nu15143266

Aquino-Bolaños, E. N., Garzón-García, A. K., Alba-Jiménez, J. E., Chávez-Servia, J. L., Vera-Guzmán, A. M., Carrillo-Rodríguez, J. C., & Santos-Basurto, M. A. (2021). Physicochemical Characterization and Functional Potential of *Phaseolus vulgaris* L. and *Phaseolus coccineus* L. Landrace Green Beans. *Agronomy*, *11*(4), 803. https://doi.org/10.3390/agronomy11040803

Bosmali, I., Kotsiou, K., Matsakidou, A., Irakli, M., Madesis, P., & Biliaderis, C. G. (2025). Fortification of wheat bread with an alternative source of bean proteins using raw and roasted *Phaseolus coccineus* flours: Impact on physicochemical, nutritional and quality attributes. *Food Hydrocolloids*, *158*, 110527. https://doi.org/10.1016/j.foodhyd.2024.110527

Boye, J., Zare, F., & Pletch, A. (2010). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International*, *43*(2), 414-431. https://doi.org/10.1016/j.foodres.2009.09.003

Capistrán-Carabarin, A., Aquino-Bolaños, E. N., García-Díaz, Y. D., Chávez-Servia, J. L., Vera-Guzmán, A. M., & Carrillo-Rodríguez, J. C. (2019). Complementarity in Phenolic Compounds and the Antioxidant Activities of *Phaseolus coccineus* L. and *P. vulgaris* L. Landraces. *Foods*, *8*(8), 295. https://doi.org/10.3390/foods8080295

Chávez-Mendoza, C., & Sánchez, E. (2017). Bioactive Compounds from Mexican Varieties of the Common Bean (*Phaseolus vulgaris*): Implications for Health. *Molecules*, *22*(8), 1360. https://doi.org/10.3390/molecules22081360

Chávez-Santoscoy, R. A., Gutiérrez-Uribe, J. A., & Serna-Saldívar, S. O. (2013). Effect of Flavonoids and Saponins Extracted from Black Bean (*Phaseolus vulgaris* L.) Seed Coats as Cholesterol Micelle Disruptors. *Plant Foods for Human Nutrition*, *68*(4), 416-423. https://doi.org/10.1007/s11130-013-0384-7

Chen, J., Liu, B., Ji, N., Zhou, J., Bian, H., Li, C., Chen, F., & Bao, J. (2009). A novel sialic acid-specific lectin from *Phaseolus coccineus* seeds with potent antineoplastic and antifungal activities. *Phytomedicine*, *16*(4), 352-360. https://doi.org/10.1016/j.phymed.2008.07.003

Corzo-Ríos, L. J., Sánchez-Chino, X. M., Cardador-Martínez, A., Martínez-Herrera, J., & Jiménez-Martínez, C. (2020). Effect of cooking on nutritional and non-nutritional compounds in two species of *Phaseolus* (*P. vulgaris* and *P. coccineus*) cultivated in Mexico. *International Journal of Gastronomy and Food Science*, *20*, 100206. https://doi.org/10.1016/j.ijgfs.2020.100206

Du, F., Zhu, M., Wang, H., & Ng, T. (2013). Purification and characterization of an a-galactosidase from *Phaseolus coccineus* seeds showing degrading capability on raffinose family oligosaccharides. *Plant Physiology and Biochemistry*, 5.

Espinosa-Ramírez, J., Mariscal-Moreno, R. M., Chuck-Hernández, C., Serna-Saldivar, S. O., & Espiricueta-Candelaria, R. S. (2022). Effects of the substitution of wheat flour with raw or germinated ayocote bean (*Phaseolus coccineus*) flour on the nutritional properties and quality of bread. *Journal of Food Science*, *87*(9), 3766-3780. https://doi.org/10.1111/1750-3841.16263

FAOSTAT. (2020). *FAO Statistical Yearbook. Food and Agriculture Organization of the United Nations*. https://www.fao.org/faostat/es/#data/QCL

Feria, M., Pérez-Santiago, A., Cuevas, D., Martínez, M., & Córdoba, F. (1996). Purification and partial characterization of a new anti-A1 lectin of *Phaseolus coccineus* collected in Oaxaca, Mexico. *Preparative Biochemistry & Biotechnology*, *26*(1), 31-46. https://doi.org/10.1080/10826069608000048

Göksel Saraç, M., Dedebaş, T., Hastaoğlu, E., & Arslan, E. (2022). Influence of using scarlet runner bean flour on the production and physicochemical, textural, and sensorial properties of vegan cakes: WASPAS-SWARA techniques. *International Journal of Gastronomy and Food Science*, *27*, 100489. https://doi.org/10.1016/j.ijgfs.2022.100489

González-Cruz, L., Valadez-Vega, C., Juárez-Goiz, J. M. S., Flores-Martínez, N. L., Montañez-Soto, J. L., & Bernardino-Nicanor, A. (2022). Partial Purification and Characterization of the Lectins of Two Varieties of *Phaseolus coccineus* (Ayocote Bean). *Agronomy*, *12*(3), 716. https://doi.org/10.3390/agronomy12030716

Hasanaklou, H. T., Pipan, B., Meglič, V., Nagl, N., & Sinkovič, L. (2024). Trypsin inhibitors in seeds and pods of *Phaseolus vulgaris*/*coccineus*: A comparative study of shaking and ultrasonic extraction methods. *Electronic Journal of Biotechnology*, *71*, 47-56. https://doi.org/10.1016/j.ejbt.2024.05.003

Hernández-Delgado, S., Muruaga-Martínez, J. S., Vargas-Vázquez, M. L. P., Martínez-Mondragón, J., Chávez-Servia, J. L., Gill-Langarica, H. R., Mayek-Pérez, N., Hernández-Delgado, S., Muruaga-Martínez, J. S., Vargas-Vázquez, M. L. P., Martínez-Mondragón, J., Chávez-Servia, J. L., Gill-Langarica, H. R., & Mayek-Pérez, N. (2015). Advances in Genetic Diversity Analysis of *Phaseolus* in Mexico. En *Molecular Approaches to Genetic Diversity*. IntechOpen. https://doi.org/10.5772/60029

Jaiswal, A. (2020). *Nutritional Composition and Antioxidant Properties of Fruits and Vegetables—1st Edition*. https://www.elsevier.com/books/nutritional-composition-and-antioxidant-properties-of-fruits-and-vegetables/jaiswal/978-0-12-812780-3

Kalloo, G. (1993). Runner bean: *Phaseolus coccineus* L. En G. Kalloo & B. O. Bergh (Eds.), *Genetic Improvement of Vegetable Crops* (pp. 405-407). Pergamon. https://doi.org/10.1016/B978-0-08-040826-2.50032-1

King, J., Leong, S. Y., Alpos, M., Johnson, C., McLeod, S., Peng, M., Sutton, K., & Oey, I. (2024). Role of food processing and incorporating legumes in food products to increase protein intake and enhance satiety. *Trends in Food Science & Technology*, 104466. https://doi.org/10.1016/j.tifs.2024.104466

Kumar, Y., Basu, S., Goswami, D., Devi, M., Shivhare, U. S., & Vishwakarma, R. K. (2022). Anti-nutritional compounds in pulses: Implications and alleviation methods. *Legume Science*, *4*(2), e111. https://doi.org/10.1002/leg3.111

Lacaille-Dubois, M.-A., & Melzig, M. (2016). Saponins: Current Progress and Perspectives. *Planta Medica*, *82*(18), 1495-1495. https://doi.org/10.1055/s-0042-119776

Li, S., Bu, T., Zheng, J., Liu, L., He, G., & Wu, J. (2019). Preparation, Bioavailability, and Mechanism of Emerging Activities of Ile-Pro-Pro and Val-Pro-Pro. Comprehensive Reviews in Food Science and Food Safety, 18(4), 1097-1110. https://doi.org/10.1111/1541-4337.12457

Luna-Vital, D. A., Mojica, L., González de Mejía, E., Mendoza, S., & Loarca-Piña, G. (2015). Biological potential of protein hydrolysates and peptides from common bean (*Phaseolus vulgaris* L.): A review. *Food Research International*, *76*, 39-50. https://doi.org/10.1016/j.foodres.2014.11.024

Marinangeli, C. P. F., & Jones, P. J. H. (2011). Whole and fractionated yellow pea flours reduce fasting insulin and insulin resistance in hypercholesterolaemic and overweight human subjects. *British Journal of Nutrition*, *105*(1), 110-117. https://doi.org/10.1017/S0007114510003156

Mariscal-Moreno, R. M., Chuck-Hernández, C., Figueroa-Cárdenas, J. de D., & Serna-Saldivar, S. O. (2021). Physicochemical and Nutritional Evaluation of Bread Incorporated with Ayocote Bean (*Phaseolus coccineus*) and Black Bean (*Phaseolus vulgaris*). *Processes*, *9*(10), Art. 10. https://doi.org/10.3390/pr9101782

Mojica, L., Gonzalez de Mejia, E., Granados-Silvestre, M. Á., & Menjivar, M. (2017). Evaluation of the hypoglycemic potential of a black bean hydrolyzed protein isolate and its pure peptides using *in silico*, *in vitro* and *in vivo* approaches. *Journal of Functional Foods*, *31*, 274-286. https://doi.org/10.1016/j.jff.2017.02.006

Mullins, A. P., & Arjmandi, B. H. (2021). Health Benefits of Plant-Based Nutrition: Focus on Beans in Cardiometabolic Diseases. *Nutrients*, *13*(2), 519. https://doi.org/10.3390/nu13020519

Ngai, P. H. K., & Ng, T. B. (2005). Phaseococcin, an antifungal protein with antiproliferative and anti-HIV-1 reverse transcriptase activities from small scarlet runner beans. *Biochemistry and Cell Biology*, *83*(2), 212-220. https://doi.org/10.1139/o05-037

Njoumi, S., Josephe Amiot, M., Rochette, I., Bellagha, S., & Mouquet-Rivier, C. (2019). Soaking and cooking modify the alpha-galacto-oligosaccharide and dietary fibre content in five Mediterranean legumes. *International Journal of Food Sciences and Nutrition*, *70*(5), 551-561. https://doi.org/10.1080/09637486.2018.1544229

Nowaková, N., & Kocourek, J. (1974). Studies on phytohemagglutinins: XX. Isolation and characterization of hemagglutinins from scarlet runner seeds (*Phaseolus coccineus* L.). *Biochimica et Biophysica Acta (BBA) - Protein Structure*, *359*(2), 320-333. https://doi.org/10.1016/0005-2795(74)90231-1

Ochoa, J.-L., & Kristiansen, T. (1978). Stroma: As an affinity adsorbent for non-inhibitable lectins. *FEBS Letters*, *90*(1), 145-148. https://doi.org/10.1016/0014-5793(78)80317-2

Orak, H., Karamać, M., Orak, A., & Amarowicz, R. (2016). Antioxidant Potential and Phenolic Compounds of Some Widely Consumed Turkish White Bean (*Phaseolus vulgaris* L.) Varieties. *Polish Journal of Food and Nutrition Sciences*, *66*(4), 253-260. https://doi.org/10.1515/pjfns-2016-0022

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Pan, W. L., & Ng, T. B. (2015). A dimeric Phaseolus coccineus lectin with anti-oxidative, anti-proliferative and cytokine-inducing activities. *International Journal of Biological Macromolecules*, *81*, 960-966. https://doi.org/10.1016/j.ijbiomac.2015.09.034

Patterson, C. A., Curran, J., & Der, T. (2017). Effect of Processing on Antinutrient Compounds in Pulses. *Cereal Chemistry*, *94*(1), 2-10. https://doi.org/10.1094/CCHEM-05-16-0144-FI

Pedrali, D., Proserpio, C., Borgonovi, S. M., Zuccolo, M., Leoni, V., Borgonovo, G., Bernardi, A. M., Scarafoni, A., Pagliarini, E., Giorgi, A., & Giupponi, L. (2022). Nutritional Characterization and Novel Use of "Copafam" Bean (*Phaseolus coccineus* L.) for the Sustainable Development of Mountains Areas. *Sustainability*, *14*(20), 13409. https://doi.org/10.3390/su142013409

Peighambardoust, S. H., Karami, Z., Pateiro, M., & Lorenzo, J. M. (2021). A Review on Health-Promoting, Biological, and Functional Aspects of Bioactive Peptides in Food Applications. *Biomolecules*, *11*(5), 631. https://doi.org/10.3390/biom11050631

Proserpio, C., Bresciani, A., Marti, A., & Pagliarini, E. (2020). Legume Flour or Bran: Sustainable, Fiber-Rich Ingredients for Extruded Snacks? *Foods*, *9*(11), 1680. https://doi.org/10.3390/foods9111680

Rațu, R. N., Veleșcu, I. D., Stoica, F., Usturoi, A., Arsenoaia, V. N., Crivei, I. C., Postolache, A. N., Lipșa, F. D., Filipov, F., Florea, A. M., Chițea, M. A., & Brumă, I. S. (2023). Application of Agri-Food By-Products in the Food Industry. *Agriculture*, *13*(8), Art. 8. https://doi.org/10.3390/agriculture13081559

Rodriguez, M., Rau, D., Angioi, S. A., Bellucci, E., Bitocchi, E., Nanni, L., Knüpffer, H., Negri, V., Papa, R., & Attene, G. (2013). European *Phaseolus coccineus* L. landraces: Population Structure and Adaptation, as Revealed by cpSSRs and Phenotypic Analyses. *PLoS ONE*, *8*(2), e57337. https://doi.org/10.1371/journal.pone.0057337

Romero-Arenas, O., Damián Huato, M. A., Rivera Tapia, J. A., Báez Simón, A., Huerta Lara, M., & Cabrera Huerta, E. (2013). *The Nutritional value of Beans (Phaseolus vulgaris L.) and its importance for Feeding of Rural communities in Puebla-Mexico*. *Vol. 2(8), 59-65*.

Saint-Eve, A., Granda, P., Legay, G., Cuvelier, G., & Delarue, J. (2019). Consumer acceptance and sensory drivers of liking for high plant protein snacks. *Journal* *of the Science of Food and Agriculture*, *99*(8), 3983-3991. https://doi.org/10.1002/jsfa.9624

Salim, R., Nehvi, I. B., Mir, R. A., Tyagi, A., Ali, S., & Bhat, O. M. (2023). A review on anti-nutritional factors: Unraveling the natural gateways to human health. *Frontiers in Nutrition*, *10*, 1215873. https://doi.org/10.3389/fnut.2023.1215873

Sánchez-Arteaga, H. M., Urías-Silvas, J. E., Espinosa-Andrews, H., & García-Márquez, E. (2015). Effect of chemical composition and thermal properties on the cooking quality of common beans (*Phaseolus vulgaris*). *CyTA - Journal of Food*, *13*(3), 385-391. https://doi.org/10.1080/19476337.2014.988182

Sánchez-Villa, C. E., Zepeda-Bautista, R., Ramírez-Ortiz, M. E., & Corzo-Ríos, L. J. (2020). Nixtamalized tortillas supplemented with proteins isolated from *Phaseolus coccineus* and huauzontle (*Chenopodium berlandieri* subsp. *Nuttalliae*) flour: Rheological, textural, and sensorial properties. *International Journal of Gastronomy and Food Science*, *22*, 100274. https://doi.org/10.1016/j.ijgfs.2020.100274

Schmidt, H. de O., & Oliveira, V. R. de. (2023). Overview of the Incorporation of Legumes into New Food Options: An Approach on Versatility, Nutritional, Technological, and Sensory Quality. *Foods (Basel, Switzerland)*, *12*(13), 2586. https://doi.org/10.3390/foods12132586

Shevkani, K., Singh, N., Chen, Y., Kaur, A., & Yu, L. (2019). Pulse proteins: Secondary structure, functionality and applications. *Journal of Food Science and Technology*, *56*(6), 2787-2798. https://doi.org/10.1007/s13197-019-03723-8

ShuMei, L., LiRong, W., MengXuan, S., & XianLiang, S. (2019). Effect of food additives on antioxidant activity of flavonoids from *Phaseolus coccineus*. *China Condiment*, *44*(5), 9-16.

Singh, B., Singh, J. P., Shevkani, K., Singh, N., & Kaur, A. (2017). Bioactive constituents in pulses and their health benefits. *Journal of Food Science and Technology*, *54*(4), 858-870. https://doi.org/10.1007/s13197-016-2391-9

Singh, N. (2017). Pulses: An overview. *Journal of Food Science and Technology*, *54*(4), 853-857. https://doi.org/10.1007/s13197-017-2537-4

Sinkovič, L., Pipan, B., Sinkovič, E., & Meglič, V. (2019). Morphological Seed Characterization of Common (*Phaseolus vulgaris* L.) and Runner (*Phaseolus coccineus* L.) Bean Germplasm: A Slovenian Gene Bank Example. *BioMed Research International*, *2019*, 1-13. https://doi.org/10.1155/2019/6376948

Teniente-Martínez, G., Bernardino-Nicanor, A., Cariño-Cortés, R., Valadez-Vega, M. del C., Montañez-Soto, J. L., Acosta-García, G., & González-Cruz, L. (2019). Cytotoxic and genotoxic activity of protein isolate of ayocote beans and anticancer activity of their protein fractions. *Journal of Food Measurement and Characterization*, *13*(2), 1040-1048. https://doi.org/10.1007/s11694-018-0019-7

Teniente-Martínez, G., Bernardino-Nicanor, A., Valadez-Vega, M. D. C., Montañez-Soto, J. L., Juárez-Goiz, J. M. S., & González-Cruz, L. (2022). *In vitro* study of the antihypertensive, antioxidant and antiproliferative activities of peptides obtained from two varieties of *Phaseolus coccineus* L. *CyTA - Journal of Food*, *20*(1), 102-110. https://doi.org/10.1080/19476337.2022.2090611

Thakur, A., Sharma, V., & Thakur, A. (2019). An overview of anti-nutritional factors in food. *International Journal of Chemical Studies*, *7*(1), 2472-2479.

Venkatachalam, K., & Nagarajan, M. (2017). Physicochemical and sensory properties of savory crackers incorporating green gram flour to partially or wholly replace wheat flour. *Italian Journal of Food Science*, *29*(4). https://doi.org/10.14674/1120-1770-IJFS808

Yeshi, K., Crayn, D., Ritmejerytė, E., & Wangchuk, P. (2022). Plant Secondary Metabolites Produced in Response to Abiotic Stresses Has Potential Application in Pharmaceutical Product Development. *Molecules*, *27*(1), 313. https://doi.org/10.3390/molecules27010313

Zhao, Q., Luan, X., Zheng, M., Tian, X.-H., Zhao, J., Zhang, W.-D., & Ma, B.-L. (2020). Synergistic Mechanisms of Constituents in Herbal Extracts during Intestinal Absorption: Focus on Natural Occurring Nanoparticles. *Pharmaceutics*, *12*(2), 128. https://doi.org/10.3390/pharmaceutics12020128