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Pulses: A way to encourage sustainable fiber consumption

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ABSTRACT

Background: The gap between recommended and actual dietary fiber consumption in Western societies is increasing largely, due to a shift towards a Western dietary pattern. This has resulted in a marked deficit in dietary fiber intake that can negatively impact the intestinal microbiota and thereby increase susceptibility to various diseases.

Scope and approach: This review investigates the potential of pulses, rich in dietary fiber and protein, to bridge this fiber gap. It highlights the role of pulses in enriching the human gut microbiota through their prebiotic properties, supporting sustainable diets, and contributing to environmental sustainability. Furthermore, we delve into the impact of diverse pulse processing methods and explore the breadth of industrially produced pulse-based products.

Key findings and conclusions: Pulses emerge as a compelling strategy to combat dietary fiber deficiency. They serve a dual purpose of promoting health through their prebiotic properties and sustainability through their high protein content and low environmental impact. The versatility of pulses enables their integration into an array of dietary patterns, making them a significant catalyst in the shift towards healthier, more sustainable diets. Despite the appeal of pulses, their underutilization highlights a missed opportunity for improving dietary fiber intake and enhancing gut health in Western societies. The broadening array of pulse-based products points towards a promising avenue for increasing pulse consumption and bridging the fiber gap.

1. Introduction

Throughout human history, the microbiota has likely undergone substantial adaptation in response to dietary changes, with food production, agriculture, and preparation all playing significant roles in shaping gut microbiota (Olm & Sonnenburg, 2021). A high-fiber diet, combined with exposure to diverse environmental microbes, akin to our human ancestors, can enrich the microbiota by increasing the presence of potentially beneficial bacterial genomes (De Filippo et al., 2017; Fu et al., 2022). Rural indigenous populations have been found to harbor substantial biodiversity in their gut microbiota. It was also shown to have bacteria better adapted to breaking down plant-based foods (Fragiadakis et al., 2019). In contrast, modern diets that are high in fat and refined sugar and low in dietary fiber have been linked to a rise in non-infectious intestinal diseases (O'Toole & Shiels, 2020). These dietary shifts may hinder the microbiota's ability to adapt, leading to microbial simplification and depriving our microbial gene pool of potentially useful environmental gene reservoirs for adapting to specific diets (Huang et al., 2023).

In 1969, Denis Burkitt published an article titled "*Related disease-related cause?"* which became the foundation for Burkitt's hypothesis (Burkitt, 1969). The hypothesis he made was simple: the Western diet is too low in fiber and is responsible for the emergence of many diseases. To counteract these multiple epidemics, more fiber must be added to diets that are too rich in refined sugars. The production and advertisement of tasty, low-cost, fiber-deficient fast foods by the food industry have more influence on people's food habits than health-care professionals have. Education, food security and a plant-based oriented diet could increase the amount of natural fiber consumed (O'Keefe, 2019).

Furthermore, the current food system faces the challenge of sustainability as it contributes significantly to climate change and loss of biodiversity and produces vast quantities of waste. In this context, pulses play a major and central role (Ferreira et al., 2021). Following resolution June 2013 of the 38th FAO Conference, the UN General Assembly, at its 68th session declared 2016 as the International Year of Pulses (IYP). The Food and Agriculture Organization of the United Nations (FAO) has been nominated to facilitate the implementation of the Year in collaboration with Governments, relevant organizations, non-

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governmental organizations and all other relevant stakeholders. Since then, February 10 of every year has been dedicated to pulses, to raise awareness of their importance in the global diet, and to consider an agricultural model driven by plant cultivation to promote sustainable nutritional solutions.

Pulses, which are an integral part of healthy dietary patterns like the Mediterranean diet, are rich in fiber. A nutritional intervention based on this diet has shown an increase in pulse consumption, associated with health benefits and modulation of the intestinal microbiota (Meslier et al., 2020). They can serve as substrates for beneficial bacteria in the microbiota, leading to benefits for human health (Rezende et al., 2021). These beneficial effects on digestive health could increase the perceived value of pulses to consumers. Nowadays, pulses are not consumed enough, partly because they are time-consuming to prepare. Processed products offer an alternative to culinary preparation but it is important to distinguish between functional foods and those that are part of the Western diet.

2. The influence of the gap between fiber consumption and recommendations on the intestinal microbiota

The term dietary fiber refers to sugars that resist and improve digestion. Defined by the Codex Alimentarius, dietary fiber is a carbohydrate polymer, with 10 or more monomeric units, that is not hydrolyzed by endogenous enzymes in the human small intestine and is defined as.

(1) Edible carbohydrate polymers that are naturally present in foods consumed.
(2) Carbohydrate polymers that were obtained from the food raw material by physical, enzymatic, or chemical means and have been shown to have a physiological health benefit as demonstrated by scientific evidence generally accepted by competent authorities.
(3) Synthetic carbohydrate polymers that showed to have a physiological effect, beneficial to health as demonstrated by scientific evidence generally accepted by the competent authorities.

However, the Codex leaves upon national authorities' discretion to decide whether the possibility to add sugars with 3–9 Degrees of Polymerization (DP) in the definition of dietary fibers; leading them with two operational definitions (Jones, 2014).

Dietary fiber consists of a wide range of different compounds, each with a characterized chemical structure and a wide range of physiological effects (He et al., 2022). They originate from cereals, legumes, fruits and vegetables. In this review, we will discuss edible dietary fibers. These latter include cellulose, hemicellulose, lignin, resistant starch (RS), pectin, gums from algae, β-glucans and oligosaccharides. The different types of dietary fiber may also be categorized according to their solubility, fermentability and physiological effects. Regarding solubility, the two primary categories are Insoluble Dietary Fiber (IDF) and Soluble Dietary Fiber (SDF). Unlike insoluble fibers that do not mix with water, soluble fibers exhibit a high affinity for water. These special physical and chemical characteristics of dietary fiber can affect our digestive physiology. Firstly, their porosity and low density can increase fecal bulk, thus helping to control the transit time, which contributes to the regulation of circulating glucose and lipid levels (He et al., 2022). Secondly, they are shaping the digesta, which is relevant to feelings of satiety and control of food intake (Capuano, 2017). Finally, they act as a fuel source for the fermentation process done by microbes, mainly in the large intestine (Gibson et al., 2017). This digestive process by colonic bacteria on fibers is known as prebiotic activity (Gibson et al., 2017). Prebiotic substances are the indigestible food component that beneficially influences the host organism by selective growth stimulation and activity of beneficial bacteria. The selective stimulation of specific microbes is determined by their enzymatic capabilities (Bedu-Ferrari et al., 2022). The human genome does not contain enough genes that code for enzymes to break down dietary fiber, which makes it impossible for human enzymes to perform this function. Additionally, if the physical structure of the dietary fiber is too complex, human enzymes are unable to reach the bonds. In contrast, different types of bacteria have varying enzymatic capacities based on their phylogenetic affiliation, which enable them to break down these bonds (Bedu-Ferrari et al., 2022). If the breakdown of dietary fiber by the gut microbiota contributes to improving health, it can be considered a prebiotic compound (Gibson et al., 2017).

The definition of dietary fiber terminology is meant to evolve, as scientific understanding and characterization of dietary fiber continue to progress. Similarly, the range of classification systems used for dietary fiber remains problematic because fiber types can vary chemically and have different physiological functions.

2.1. The gap between food-based dietary guidelines and consumption of dietary fiber in europe

As an example in this review, Europe represents a variety of food cultures and dietary habits which are documented with existing data related to the consumption of fiber and pulses (Miller et al., 2021). This example can serve as a proxy for the majority of industrialized countries, which retain some of their traditional eating habits while being exposed to the Western diet because of globalization. The dietary guidelines strategies are designed to support professionals in healthcare, influence consumer behavior, and, in some countries, inform a range of national food, nutrition, and health policies and programs (Herforth et al., 2019). In 2019, the World Health Organization (WHO), requested a meta-analysis to establish recommendations based on the effects of dietary fiber (Reynolds et al., 2019). This study suggests that a minimum fiber intake of 25 to 29 g/day has a protective effect against several diseases. Additionally, the analysis of prospective studies shows dose-response relationships with all-cause mortality, total cancer deaths, total cardiovascular disease deaths and incidence, stroke incidence, and incidence of colorectal, breast, and esophageal cancer (Reynolds et al., 2019). This suggests that increased intake could potentially offer additional benefits. The European Food Safety Authority (EFSA) also recommends a dietary fiber intake of more than 25 g/day. An analysis of several European countries reveals that the recommendations, at the national level, of dietary fiber intake are at least 25 g per day, indicating a fair degree of uniformity among those countries in the definition of dietary fibers (Stephen et al., 2017). Moreover, a study by Herforth and collaborators focused on the analysis of food-based dietary guidelines in different countries around the world. The authors concluded that national recommendations for dietary fiber intake are relatively homogeneous among European countries and all national authorities promote their consumption (Herforth et al., 2019). The European Union suggests a nutritional claim for food products with over 10 g of dietary fibers, but does not provide any details on the physicochemical properties of these fibers for labeling purposes.

Although there is some consistency in the guidelines, fiber intake is lower than recommended. Even though it is difficult to measure precisely the level of dietary fiber consumption, several studies have been done across Europe to evaluate dietary fiber intake among the European population. The meta-analysis made by Stephen et *al* shows that the average consumption of dietary fibers in Europe was around 21 g/day, without any specification on the nature of dietary fiber (Stephen et al., 2017). In a pilot study, the authors aimed to characterize the type of fiber consumed by the population using the FiberTAG questionnaire (Neyrinck et al., 2020). This tool, designed to assess prebiotic dietary fiber intake, is a food frequency questionnaire that covers 12 months and extensively records both soluble and insoluble dietary fiber intake, as well as prebiotic (oligo) saccharide intake. Their findings indicate that, even in this well-informed population with high fiber consumption (38 g/day), less than 4% of fiber intake can be attributed to pulses (Neyrinck et al., 2020). This highlights the importance of pulses as an opportunity to increase dietary fiber consumption.

2.2. Dietary fiber and human gut microbiota composition

The ancestral human diet is believed to have had a significantly higher fiber intake, surpassing 100 g/day (Armet et al., 2022). This fiber-rich diet had a profound influence on the composition of the intestinal microbiota by providing fermentable substrates that promote the growth of potentially beneficial bacteria. Moreover, the fermentability of ancestral dietary fibers exceeded that of modern foods (Armet et al., 2022). From an evolutionary standpoint, the human microbiota has undergone extensive co-evolution with its human host over thousands of years (Groussin et al., 2020). Research has further revealed the co-evolution of bacterial species in the intestinal microbiota with their human hosts, influenced by factors like inter-individual transmission, geographical proximity, and dietary changes (Sanders et al., 2023). Key species that have co-evolved with humans and exhibit characteristics indicative of host dependence have been identified through studies on the evolution of intestinal bacterial species (Suzuki et al., 2022). These key species play a critical role in shaping the symbiotic relationship between humans and their gut microbiota. However, dietary shifts over time may have disrupted the co-diversification signals between humans and their gut microbiota, potentially affecting the composition, diversity, and interactions of gut microbial species with their human host (Sanders et al., 2023; Suzuki et al., 2022). The loss of microbial signals that were historically part of human biology could result in the misregulation of important systems, including immune function, metabolism, and central nervous system function. This loss could be a causative or contributing factor to the many non-communicable chronic diseases presently rising in industrialized societies (Sonnenburg & Sonnenburg, 2019). Despite the observed spatial and temporal variation in fiber diversity and abundance in the past, our ancestors developed evolutionary adaptations to ensure a consistent daily intake of fiber from a range of sources. However, it is concerning how much lower contemporary fiber consumption is (Huang et al., 2023). The impact of this dietary transition on the composition of the intestinal microbiota has been investigated through a comparative analysis of the microbiota of children in Burkina Faso who adhere to a rural diet close to that of our ancestors, and European children who follow a Western diet (De Filippo et al., 2017). The study suggests that a fiber-rich diet promotes the growth of beneficial bacteria producing short-chain fatty acids (SCFA) like propionate and acetate, benefiting blood sugar regulation, lipid/protein synthesis, and cholesterol production. Additionally, a correlation is observed between the microbiota's polysaccharide degradation and the host's caloric extraction, influencing survival and physical fitness (De Filippo et al., 2017). Notable differences in gut microbiota composition have also been observed among Asian immigrants. Upon their arrival to the United States, these immigrants undergo significant shifts in their gut microbiota, marked by a decrease in diversity and a change from *Prevotella* to *Bacteroides* dominance, and in fiber-degrading enzymes (Vangay et al., 2018). These alterations are especially evident in obese and second generation immigrants, persisting for several decades. These changes in the gut microbiota may be attributable to shifts in diet together with changes in lifestyle and environment (Vangay et al., 2018). Dietary patterns significantly influence the composition of the gut microbiota, to the extent that individuals can be clustered based on this composition. Specifically, the presence of dominant bacteria genera like *Bacteroides* and *Prevotella* characterizes distinct gut microbial enterotypes, each associated with particular long-term dietary habits (MetaHIT Consortium (additional members) et al., 2011). For instance, a *Bacteroides*-rich enterotype often correlates with high consumption of protein and animal fat, while a *Prevotella*-dominant enterotype is associated with a carbohydrate-heavy diet (MetaHIT Consortium (additional members) et al., 2011). While some changes can be reversed, a study using mice with a humanized microbiota demonstrated that certain alterations become permanent over successive generations. In particular, a low-fiber diet leads to a gradual decline in intestinal microbial diversity across generations, and simply reintroducing dietary fiber is insufficient to restore this diversity (Sonnenburg et al., 2016).

2.3. Gut microbiota: a dynamic ecosystem for fiber degradation

Several studies have highlighted the gut microbiota to be one of the most specialized and sophisticated ecosystem involved in the breakdown of complex polysaccharides (Bedu-Ferrari et al., 2022). The functionality of the gut microbiota to break down complex carbohydrates is reflected in an arsenal of prominent and highly diverse carbohydrate-active enzymes (CAZymes)-encoding genes, which comprise 1%–5% of the predicted coding sequences in most bacterial genomes (Bedu-Ferrari et al., 2022). Diverse classes represent the numerous CAZyme families: glycoside hydrolases depolymerize carbohydrate substrates by hydrolyzing glycosidic linkages; glycosyl-transferases lead the formation of glycosidic bonds; carbohydrate esterases catalyze the hydrolysis of carbohydrate esters; and polysaccharide lyases operate non-hydrolytic cleavage of glycosidic bonds (Wardman et al., 2022). The breakdown of dietary fiber by commensal bacteria is based on complex mechanisms coordinated at the molecular level. It has been shown that, to varying extents among *Bacteroidetes* species, bacterial genomes conserve a breakdown and importing machinery that is encoded within clusters of contiguous and co-regulated genes, known as Polysaccharides Utilisation Loci (PUL) (Wardman et al., 2022). The PUL systems constitute the major strategy for harvesting carbohydrates deployed by *Bacteroidetes* bacteria. Nevertheless, analogs of *Bacteroidetes* PUL have been described in bacteria belonging to other *phyla* (Glover et al., 2022). Numerous bacteria possess glycoside hydrolases capable of breaking down the mucins that constitute the protective barrier of the gut (Glover et al., 2022). These GHs are particularly active in the absence of dietary fiber, whereas the presence of fiber inhibits their activity (Armet et al., 2022). A diet rich in fiber enhances the availability of dietary fiber as a substrate for the microbiota, thereby preserving the integrity of the intestinal barrier and mitigating the risk of inflammation and infection (Shen et al., 2023).

Once the fibers are broken down, they are fermented by the anaerobic colonic microbiota, leading to the production of SCFA, mainly acetate, propionate and butyrate. The catabolism of branched-chain amino acids, such as valine, leucine, and isoleucine, can also result in the production of branched SCFA like isobutyrate and isovalerate, albeit to a lesser extent. Furthermore, microbiota fermentation intermediates like lactate or ethanol can also be metabolized into SCFA (Flint et al., 2012). These SCFA serve as primary carbon energy source for colonocytes and are considered key factors of the gut microbiota that contribute to the beneficial effects on human health (Flint et al., 2012). It is important to note that the gut microbiota produces various other classes of metabolites, including bile acids and amino acid derivatives such as tryptophan metabolites, which may also have essential signaling functions (Agus et al., 2018). Metabolites produced by the intestinal microbiota play a crucial role in participating to the development and maturation of the host, offering a promising avenue for investigating the biological mechanisms involving the gut microbiota. Numerous studies aim to establish correlations between the microbiota taxonomic composition and various pathologies, which can partially explain health benefits of dietary fibers.

3. Pulses: an underappreciated resource with prebiotic potential

Legumes comprise a large and important group of flowering plants, named the Fabaceae family, produced on an agricultural basis. Widely distributed, this family is the third-largest land plant in the number of species. Legumes harvested exclusively for dry grains, which include dry beans, chickpeas, lentils, and peas are known as pulses. Even though the latter are small, this category of plants is particularly rich in proteins, dietary fibers, polyphenols, minerals and vitamins while having a low energy index (Margier et al., 2018). These nutritional properties make them very interesting for multiple applications. Today, there is a focus on the use of pulses, in combination with cereals, as an alternative for reducing animal protein intake (Szczebyło et al., 2020). This recommendation is in line with the objectives to reduce the part of greenhouse gas emissions by the food industry. Pulses are also an important lever for increasing the proportion of dietary fiber ingested. This has been observed in the American and Canadian populations. Indeed, individuals who incorporated pulses into their diet, alongside an equivalent consumption of cereals, were found to have a higher intake of total dietary fiber. This intake even exceeded the minimum recommended levels (Thompson, 2021). Several studies emphasize the significance of recognizing the involvement of the gut microbiota in the beneficial effects linked to pulses (Armet et al., 2022).

3.1. *Recommendations and consumption of pulses in europe*

Several studies highlight that pulses confer health benefits (Fig. 1). There is evidence supporting that regular consumption of pulses increases glucose tolerance and insulin sensitivity (Becerra-Tomás et al., 2018). Moreover, pulses consumption, especially lentils, can lower the risk of Type II Diabetes (Becerra-Tomás et al., 2018). Pulses also help in cancer prevention. Bioactive compounds such as polyphenols, derived peptides, and other compounds like flavonoids and saponins, exhibit beneficial effects, such as antioxidant, anti-inflammatory, and cytotoxicity towards cancer cells (Serventi et al., 2022). Moreover, a high intake of pulses has been associated with lower cancer-related mortality (Veronese et al., 2018). In terms of cardiovascular health, bioactive compounds, such as gamma-aminobutyric acid (GABA) and derived peptides in pulses, help to regulate cardiovascular function and modulate cholesterol levels (Garcés-Rimón et al., 2022). Additionally, high pulses consumption is associated with reduced risks of cardiovascular and coronary diseases (Mendes et al., 2023). Given the difficulties in classifying pulses in a single category, it is challenging to quantify their consumption and their place in nutritional recommendations given by national authorities. Using the FAO's online repository of food-based dietary guidelines (FBDG), a study was conducted to evaluate the inclusion of pulses in global FBDG. The results showed that in Europe, 40% of countries classify pulses as 'Protein-rich foods', 14% include them in the 'Vegetables, legumes, and fruits' category, and 11% classify them as their own group called 'Legumes' (Hughes et al., 2022). The terminology used by different national authorities in key messages to define pulses shows that 'Legumes' was the term most commonly employed (Hughes et al., 2022). In Europe, very few countries recommend a precise quantity of pulses to be consumed, however, their integration in people's meal are more often adopted when there is a recommendation (Hughes et al., 2022). Although there is no universally accepted daily target, a recent review concluded that a reasonable serving size to be promoted internationally could be based on 100 g of cooked beans, lentils, chickpeas, or peas per day (Marinangeli et al., 2017). Based on data extracted from the 2018 Global Dietary Database (GDD), an estimation of the amount of pulses consumed per country estimated the median consumption in Europe to be 14.9 g/day, indicating that Europe has the lowest reported level of consumption worldwide (Hughes et al., 2022). Due to their nutrient composition, which is high in dietary fiber and plant-based protein, legumes pose a unique positioning challenge. Nevertheless, with the growing focus on sustainable eating patterns, innovative positioning or perhaps repositioning of legumes might be a valuable consideration within the FBDG (Thompson, 2021).

3.2. *Nutrients present in pulses*

Pulses encompass both nutritious elements like proteins, vitamins, minerals, and dietary fibers that boost health and energy, and antinutrients like protease inhibitors or polyphenols-protein complexes, which can reduce protein bioavailability.

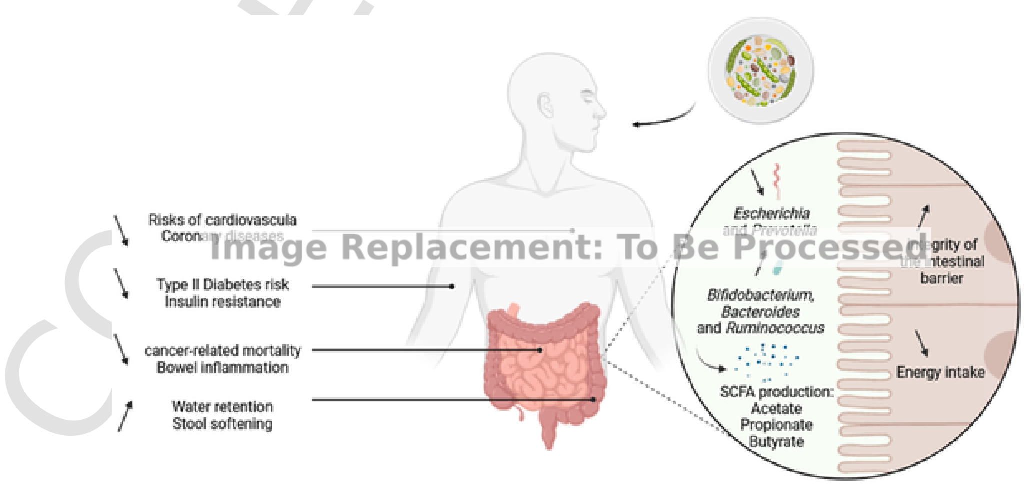

Fig. 1. The multifaceted health benefits of pulses
This figure depicts the interplay between diet-induced gut microbiota changes and their systemic health implications. On the left, health risks are connected to gut health alterations, such as the increased risk of cardiovascular and coronary diseases, Type II Diabetes risk with insulin resistance, and cancer-related mortality associated with bowel inflammation. It also indicates the gastrointestinal benefits of water retention and stool softening. The right side of the diagram reveals shifts in gut microbiota composition, with a decrease in bacterial genera like Escherichia and Prevotella, and an increase in health-promoting bacteria such as Bifidobacterium, Bacteroides, and Ruminococcus. These beneficial shifts are accompanied by enhanced production of short-chain fatty acids (SCFAs) — acetate, propionate, and butyrate — crucial for the integrity of the intestinal barrier and regulation of energy intake. Such microbiota alterations may underpin health benefits, including mitigated weight gain and better glycemic control, highlighting the importance of microbiota diversity and inter-individual variability.

3.2.1. *Dietary fibers*

Numerous studies have been carried out to characterize fibers present in pulses (Table 1). The level of dietary fiber varies according to the type of pulses and the analytical method used, but overall data show fiber levels higher than 10 g/100 g (Table 1). Some authors even show fiber contents above 20 g/100 g for chickpeas, lentils, or dry peas (John et al., 2023). These levels exceed those found in fruits and vegetables, which generally contain less than 5 g of fiber per 100 g of food (Dhingra et al., 2012). Depending on the species of pulses, quantitative differences in the concentration of fibers have been found (Table 1).

Types of fibers present in pulses include long-chain soluble and insoluble polysaccharides, resistant starch, and short-chain oligosaccharides, galactooligosaccharides (GOS), belonging to raffinose family oligosaccharides (RFO). In a large range of pulses, there is a majority of insoluble fibers with an IDF/SDF ratio higher than one. Among these insoluble fibers found in pulses, there are cellulose, a structural component of the primary cell wall in green plants, and lignin. As structural component of the plant cell wall, lignin is sometimes considered as a dietary fiber, especially in woody plants, but it is not classified as a polysaccharide and is considered chemically inert. Also part of the insoluble fibers found in pulses, hemicellulose describes all the polysaccharide components of the cell wall other than cellulose. Hemicelluloses are diverse, branched polymers made up of various sugars, with solubility dependent on the specific sugar residues attached.

Interestingly, pulses are particularly rich in oligosaccharides, which include, galactooligosaccharides (GOS: raffinose, stachyose, and verbascose) and fructooligosaccharides (FOS: kestose and nystose) (Elango et al., 2022). Raffinose, stachyose, and verbascose are soluble carbohydrates belonging to RFO. They are composed of alpha-D-galactopyranose, alpha-D-glucopyranose and beta-D-fructofuranose

Table 1
The physicochemical characteristics of dietary fibers found in four varieties of dried pulses.

Physico chemical characteristics	Polysaccharide group	Non-Starch Polysaccharides (NSP) (DP ≥ 10)			Oligosaccharides (DP ≥ 2)					RS	References
	Polysaccharide Class	Cellulose (g/100 g)	Hemicellulose (g/100 g)	Pectin (g/100 g)	alpha-Galactooligosaccharides (α-GOS): RFO (Raffinose Family Oligosaccharide)			Fructooligosaccharides (FOS)		Resistant Starch (RS) (DP ≥ 10) (g/100 g)	
	Oligo-Poly-saccharide	Unbranched polysaccharide consisting of glucose unit linked by bonds	Arabinoxylan (xylose framework linked in side chain to arabinose residues).	linear chain (300 < DP < 1000) of galacturonic acid associated with other sugars	Raffinose (mg/g)	Stachyose (mg/g)	Verbascose (mg/g)	Kestose (mg/g)	Nystose (mg/g)	RS1 & RS2	
	Osidic bonds	β (1–4)	α(1–2) α(1–3) β(1-1) β(1–4)	α(1–2) α(1–3) α(1–4) α(1–5) α(1–6) β(1–2) β(1–5)	α(1–2) & α(1–6)	α(1–2) & α(1–6)	α(1–2) & α (1–6)	α(1–2) & β(2–1)	α(1–2) & β(2–1)	Physically inaccessible. α(1–4) & α (1–6)	
	Water solubility	–	+ +	+ +	+ + +	+ + +	+ + +	+ + +	+ + +	–	
	viscosity	–	+ +	+ +	–	–	–	–	–	–	
	Fermentability	+	+ +	+ +	+ + +	+ + +	+ + +	+ + +	+ + +	+ +	
Sources	Chickpea	[1–7]	6	3	[4–5]	[11–18]	[0–1]	0	5	3	(Brummer et al., 2015; Njoumi et al., 2019; Siva et al., 2019)
	Lentil	[1–3]	[1–4]	2	[2–5]	[18–23]	[9–14]	3	0	2	(Brummer et al., 2015; Njoumi et al., 2019; Siva et al., 2019)
	pea	[2–6]	[0–4]	[2–3]	[6–31]	[13–21]	[16–30]	–	–	–	(Brummer et al., 2015; Fan et al., 2014)
	bean	2	8	–	[2–9]	[7–38]	[1–26]	30	1	2	(Brummer et al., 2015; Fan et al., 2014; Njoumi et al., 2019; Siva et al., 2019)

This table describes the physico-chemical characteristics and concentrations of the main dietary fibers found in four of the most widely consumed pulses in Europe: peas, beans, chickpeas and lentils.

joined in sequence by α(1–6) and α(1–2) glycosidic linkages, respectively. Stachyose is a tetrasaccharide composed of two galactose units, that transform into verbascose, a pentasaccharide, when an additional galactose molecule is incorporated. RFO are widely present in most pulses and many plants, as they increase tolerance to freezing. Starch is the major carbohydrate in pulses accounting for nearly 50% portion of carbohydrates (Kadyan et al., 2022). Starch consists of two types of glucose polymers - amylose (linear chain) and amylopectin (branched chain), which are chemically connected by α(1–4) and/or α(1–6) glycosidic bonds. The nature of the bonds makes them digestible by host enzymes. However, a smaller proportion of starch exists in an indigestible form due to several properties. Firstly, some starch is physically inaccessible, making it indigestible (RS1). Additionally, certain starch granules possess a unique resistance to gelatinization (RS2). The native RS is relatively similar among pulses and is around 2 g/100 g (Table 1). Finally, the starch in pulses can be transformed into retrograde starch (RS3). This transformation occurs when the starch is cooked and subsequently cooled. During the cooling process, the starch chains rearrange themselves into a structure that is more resistant to digestion, hence behaving more like dietary fiber (WangHasjim, Wu, Henry, & Gilbert, 2014). Consequently, resistant starch demonstrates physical inaccessibility, resistant granules, and heat-induced modification that collectively impede digestion by human enzymes. The amount of RS in raw, baked, and boiled pulses varies significantly due to intrinsic (amylose to amylopectin ratio, physico-chemical properties) and external factors (processing methods) (Birt et al., 2013).

3.2.2. *What are the other nutrients present?*

Glycosides are not the only component of pulses. They are made up of other bioactive compounds like proteins, minerals, vitamins, phytic acid, protease inhibitors, and polyphenols.

From a nutritional perspective, pulses are particularly interesting because they can contain protein levels reaching up to 25% (Rajpurohit & Li, 2023). Among essential amino acids, pulses are a good source of lysine, which is often low in cereal grains. Another characteristic of pulses is that they are packed with other nutritional compounds, which may interact with the biological activity of the body. The mineral content of pulses is generally high in potassium, magnesium, iron, and manganese. Other minerals of interest for the pulse family include zinc, copper, selenium, and calcium (Hall et al., 2017). Hall et *al* show a great variability of mineral content between the type and species of the different pulses.

Pulses have been recognized as a source of B vitamins (Margier et al., 2018). However, other forms are present and are collectively summed as part of the total folate content. In addition to folates, pulses are a good source of thiamin and riboflavin (Margier et al., 2018).

Phytic acid**,** myo-inositol-(1,2,3,4,5,6) hexakis-phosphate and its salts represent the main source of the phosphorus in pulse (Sinkovič et al., 2022). Excessive phytic acid in the diet can have a negative effect on the mineral balance due to the formation of insoluble complexes with essential minerals, such as Cu, Zn, Co, Mg, Fe and Ca, which negatively alter their bioavailability.

Polyphenols constitute a large group of bioactive phytochemicals that include multiple sub-classes such as flavonoids, stilbenes, phenolic acids, and lignans. Pulses can be a useful natural source of phenolic acids, flavonoids, isoflavones, and tannins (Hall et al., 2017), whereas, there is a great variability in terms of polyphenols composition in different pulses (Elessawy et al., 2020).

Recently, Santanatoglia and collaborators developed an extraction method and an analytical HPLC-DAD method to determine the main phytosterols in 22 legume samples (Santanatoglia et al., 2023).

Concerning protease inhibitors, there is a high number of isoforms of the Kunitz and the Bowman–Birk families that vary with the pulse species and variety (Pedrosa et al., 2021). They both have the power to inhibit trypsin and chymotrypsin enzymes. However, in the Western diet, no inhibition of gut protein digestion has been reported, mainly because pulses are cooked to theirs consumption, leading to the destruction of protease inhibitors due to their thermal-lability property (Pedrosa et al., 2021).

3.3. *Prebiotic potential of pulses*

Pulses offer promising prebiotic potential based on their content in dietary fibers. Acting as fermentation substrates for gut bacteria, dietary fibers found in pulses position them as invaluable food sources for fostering a healthy gut microbiota. Improvements in analytical strategies for the identification of prebiotic saccharides are also needed (Kouzounis et al., 2022).

3.3.1. *Raffinose family oligosaccharides: RFO*

Composed of α(1–6)-galactosides linked to a sucrose molecule (Table 1), these oligosaccharides are indigestible due to the absence of α-galactosidase enzymes in the human genome (Mao et al., 2014). Nevertheless, an observational study reported that a short-term diet supplemented with RFO modulated the composition of the gut microbiota, increasing the relative abundance of beneficial bacteria that produce butyrate and acetate, such as *Faecalibacterium prausnitzii* and *Bifidobacterium* species, respectively (Fernando et al., 2010). Beyond the modulation of the gut microbiota, Elango and co-workers explore the diverse health benefits of RFO. Evidence demonstrated the ability of RFO to improve iron availability, prevent non-alcoholic fatty liver disease by inhibiting lipid accumulation, reduce fecal ammonia and indole levels, and they can have anti-allergic, anti-obesity, and anti-diabetic effects (Elango et al., 2022).

Notably, RFO are responsible for flatulence in humans and animals, which limits the widespread adoption of diets with high RFO content, such as those containing pulses, especially for individuals sensitive to gas. However, gradually introducing pulses into one's diet can allow individuals to adapt and minimize the side effects of RFO (Bellini et al., 2020).

3.3.2. *Resistant starch*

Zhou and co-workers conducted an *in vitro* investigation to examine the impact of resistant starch from peas on the fecal composition of five healthy donors. Their findings revealed that the structural differences of RS determine the degradation pattern of the substrate, the production of SCFA, and the specific microbiota involved in its degradation, thereby influencing the microbial community. At the genus level, resistant starch increased the levels of beneficial bacteria, such as *Bacteroides*, *Blautia*, *Collinsella*, *Eubacterium rectale* group, *Bifidobacterium*, and *Ruminococcus*, while potentially harmful bacteria like *Escherichia* and *Prevotella* decreased (Zhou et al., 2021). Recently, Kadyan and collaborators reviewed the numerous positive effects associated with RS from dietary pulses, suggesting RS can increase the diversity of the gut microbiota, improve insulin sensitivity, and boost the concentration of SCFA. Additionally, it can decrease body fat mass, cholesterol, and the risk of obesity, colitis, and colorectal cancer (Kadyan et al., 2022). RS in pulses also help to enhance glucose tolerance and insulin sensitivity, leading to a reduction of diabetes-related complications (Bozkır et al., 2023). However, the bacterial bioavailability of RS can vary depending on the complexity of its structure, partly leading to inter-individual variability in the response to a RS-supplemented diet.

3.4. *Availability of nutrients and the matrix effect*

The matrix effect is a crucial consideration in microbiota studies as it influences the bioavailability of nutrients for microbial fermentation. The matrix can be defined as the nutrient and non-nutrient components of foods and their molecular configuration, i.e. chemical bonds. The matrix effect is a relatively new concept, which has emerged in the fields of nutrition and food science. This effect can be defined as two foods with strictly identical composition but divergent matrices resulting in different impacts on the body, and therefore different long-term effects on health (Fardet, 2015). Indeed, the bioaccessibility and bioavailability of a nutrient are governed by the physical properties of the food matrix, which affects the efficiency of the physical, enzymatic, and chemical digestion processes (Fardet, 2015). Pulses are in a food group where physical structure plays an important role in the nutritional health value. The matrix structure of pulses before consumption is very dense. The seeds are composed of various types of cells, each consisting of a rigid cell wall encapsulating starch, more or less gelatinized granules and protein clusters (Fardet, 2015).

In beans, partial gelatinization preserves the crystalline structure of the starch, ensuring the preservation of its structure and physical integrity (Noah et al., 1998). This ultimately makes the seed resistant to digestive enzymes, which allows the starch to be digested very slowly. In their study, Noah and collaborators measured that 17% of the starch was not digested in the upper part of the intestinal tract, leading the undigested starch and fibers to reach the colon where it is fermented up to 99% by the gut microbiota (Noah et al., 1998). Recently, a research investigation evaluates the influence of cellular integrity on the fermentability by gut microbiota using pinto beans with intact or enzymatically pre-hydrolyzed cell walls. The findings indicated a variation in the bacterial fermentability of beans with modified cell walls, proposing that the intactness of the cell wall physical structure has a significant role in modulating metabolic processes of the gut microbiota (Guan et al., 2020). The complexity of the food matrix structure encompasses a vast array of nutrients, making it challenging to predict their metabolic interactions with bacteria (Johnson et al., 2019). This underlines the importance of consuming foods with complex matrices, such as pulses, as they contain diverse nutrients that can synergistically interact and potentially promote health benefits through the gut microbiota.

3.5. Gut microbiota benefits of pulses-based dietary fibers

Evidence suggests that whole pulses, such as pinto beans and chickpeas, along with cooked navy bean powder and pulse-derived fiber like lupin kernel fiber, can modulate the composition of the gut microbiota (Marinangeli et al., 2020) (Fig. 1). In the research conducted by Smith et *al*, a noteworthy elevation of daily fiber intake, approximately 20 g/day, was observed when 17–30 g of lupin fiber was infused into a variety of foods compared to the control group. Even though there was no significant alteration in the total quantity of bacteria, the consumption of lupin fiber was associated with an increased presence of *Bifidobacterium* spp., and a decrease in the groups of *Clostridium ramosum*, *Clostridium cocleatum*, and *Clostridium spiroforme* (Smith et al., 2006). Furthermore, lupin fiber intake hinted at a decrease in the *Bacteroides-Prevotella* genera. Analysis of individual responses indicated that most of the subjects drove an increase of *Bifidobacterium* spp. and the reduction of the aforementioned *Clostridium* group (Smith et al., 2006). Contrastingly, in Lambert et *al*. study, the introduction of yellow pea hulls did not lead to changes in the abundance of specific bacterial families, genera, and species. However, in both the placebo and yellow pea fiber groups, there was a distinguishable increase in 16s RNA copies for *C. leptum* (cluster IV), *Clostridium* cluster I, and *Roseburia* spp., when compared to baseline (Lambert et al., 2017). Alongside, pea fiber consumption was associated with reduction in body weight, body fat, energy intake, and postprandial glucose responses (Lambert et al., 2017).

4. Pulses: stepping stones toward a healthy and sustainable diet

Pulses are not only interesting from a nutritional aspects but also from an agro-ecological point of view: they are part of a sustainable food context (IPCC, 2022).

4.1. The contribution of pulses to a sustainable diet

On December 2, 2021, the reform of the European Common Agricultural Policy (CAP) was formally adopted. In application since 2023, this new legislation paves the way for a fairer, greener and more performance-oriented CAP. It will aim to secure a sustainable future for Europe's farmers, to provide more targeted support for small farms, and to give EU countries more flexibility to adapt measures to local conditions. Pulses play two different roles in this new policy by firstly reducing Greenhouse Gas (GHG) emissions and secondly supporting biodiversity. Indeed, pulses have a low carbon footprint as they contribute to fix nitrogen in crops. The ability of pulses to fix biologically atmospheric nitrogen in this symbiotic association allows creating a continuous supply of nitrogen in the agroecosystems without the use of additional artificial fertilizers (Clúa et al., 2018). This nitrogen-fixing property allows pulses to be a good candidate for crop rotation. This characteristic may reduce GHG emissions compared to agriculture based on nitrogen fertilizer systems (Clúa et al., 2018). The high-quality organic matter released by pulse plants in the soilboost fertility by facilitating nutrient circulation and promoting water retention (Ferreira et al., 2021). Thus can result in an improvement in yields, with a limited impact on the environment. Crop diversification with pulses plants is an important resilience factor, with positive effects on both soils and carbon storage through the management of land cover, water resources, biodiversity, and food production (Ferreira et al., 2021).

The ecological benefits of pulses are of great importance in the context of promoting sustainable agriculture and dietary habits. Currently, more than one-third of the earth's land surface is dedicated to global food production, which contributes to about 30% of human-caused GHG emissions and poses a significant environmental threat (Crippa et al., 2021). Recognizing the need to evaluate the environmental sustainability of our food and diets, there is a growing understanding that assessing only the health impacts is insufficient. The impact of our food choices on the planet has far-reaching consequences for present and future generations. Neglecting sustainability considerations when evaluating diets can worsen the ongoing environmental crises, ultimately jeopardizing our health and well-being. In this regard, pulses may be considered a fundamental component in transitioning toward more sustainable agri-food systems and diets in Europe (Ferreira et al., 2021). By incorporating pulses into our diets, we can contribute to reducing the environmental footprint of the food system while simultaneously promoting our well-being (Ferreira et al., 2021).

4.2. Pulses as dietary fiber on the plate

Pulses have been cultivated and consumed for thousands of years. They are easy to grow and preserve, they have been the staple food of the European diet. One of the major advantages of pulses is their low cost, especially when compared to other protein sources (Rajpurohit & Li, 2023). In addition, the seeds can be stored for a very long time without any treatment, which preserves them from food waste. Traditional European food includes a large number of dishes based on pulses, often in the form of stew. In the second half of the 20th century, pulse production and consumption fell in favor of meaty and more energy-rich foods (Calles et al., 2019). This drop in consumption can be attributed to the industrialization of prepared food sold in supermarkets, which requires less preparation time. A review suggests that one strategy to refocus on pulses consumption, is to educate the population on the simple steps of food preparation (Eisenberg & Imamura, 2020).

Today, pulses are back on the plates and the food industry has begun to provide new applications for pulses. They are used in many innovate food products like vegetarian meat or high-protein meals. More than 3500 new pulse-based products were introduced in the European food market, particularly in the UK, France, Germany, Spain and Italy in the period 2010–2014 (Hamann et al., 2019). Those products are mainly based on chickpeas (31%), peas (30%), beans (25%), and lentils (14 %) of which only 13% are organic (Hamann et al., 2019). Herein, we will compare the implications of home cooking and industrial preparation methods for pulses, specifically discussing the advantages and disadvantages of each and their impact on dietary fiber content (Fig. 2).

4.2.1. Effect of raw pulse preparation methods on dietary fiber

To maximize the multiple nutritional benefits of pulses and elevate the nutritive content of food products, several preparation methods have been devised over the years. These techniques, which include home-based processes like soaking, cooking, germination, and fermentation, will be discussed in the subsequent sections.

Soaking consists of the rehydration of seeds in water. During soaking, some metabolic processes can take place and usually affect the soluble carbohydrate (Njoumi et al., 2019). A study of the impact of food preparation processes on the fiber content of a traditional Tunisian dish shows that traditional soaking in water (i) reduces the total α-GOS content due to partial leaching and enzymatic degradation occurring inside and outside the seeds and (ii) induces partial solubilization of IDF with a concomitant increase in SDF. Combine with cooking, this method further decreased the total α-GOS level together with an increased IDF (Njoumi et al., 2019).

Cooking. Overall, cooking treatments cause significant decreases in carbohydrate fractions (Satya et al., 2010). In another study, cooking led to a significant decrease in RS content in cook beans (from 297.3 to 367.2 g/kg beans to 35.9–43.2 g/kg dry matter) (Wang et al., 2010). This reduction is attributed to the destruction of amylase inhibitors during the cooking process (Wang et al., 2010). Heat treatment, in particular, the cooking and cooling stages have been shown to increase the proportion of resistant starch in cooked pulses (3.75–4.66% of pulse dry weight basis) compared to many other cooked foods (Brummer et al., 2015). Another research effort examined the total dietary fiber content of beans, chickpeas, and flageolets, after being boiled post-soaking or canned. The findings show that boiling kidney beans, white beans, and chickpeas typically increase their total fiber content, while canning tends to reduce it (Margier et al., 2018). The decreases are 44%, 33%, and 22% for kidney beans, white beans, and chickpeas, respectively (Margier et al., 2018).

Germination A comparative study was conducted on chickpeas and green peas to evaluate the levels of digestible and resistant starch, both before and after germination. The findings suggest that while germination did not significantly alter the composition of digestible and resistant starch, it led to a substantial decrease in galactooligosaccharides (Erba et al., 2019).

Fermentation processes have been adopted for thousands of years as a technique for producing and preserving foods with improved nutritional and organoleptic characteristics. Fermentation is a biochemical process induced by microorganisms and their enzymes, which involves the use of ferments to transform organic matter. The microorganisms used for this process are generally bacteria or yeasts. This method allows the development of new flavors and textures in the food matrix. It is also used to improve the bioaccessibility and bioavailability of nutrients (Hotz & Gibson, 2007). On the other hand, fermentation can contribute to food safety by inhibiting the growth of pathogenic bacteria through the antimicrobial activity of lactic acid. Overall, an analysis of the literature shows that fermentation has allowed a significant reduction in galactooligosaccharides factor content in various pulses (Arbab Sakandar et al., 2021).

4.2.2. Processed food supplemented with pulses

To increase their consumption, one strategy suggested by different national dietary guidelines is to use pulses or nuts and seeds in mixed dishes as a substitute for other foods that are often over-consumed and/or higher in saturated fat, sodium, or refined carbohydrates (Monteiro et al., 2018). Within the broad variety of pulse-containing food products available in the market, it is valuable for consumers to identify those that are health-beneficial. Recognizing and distinguishing between these contrasting choices is vital for enlightened and health-conscious dietary decisions.

4.2.2.1. Functional foods in the industrial landscape. Among the diverse food options, functional foods stand out, defined as 'any food or modi-

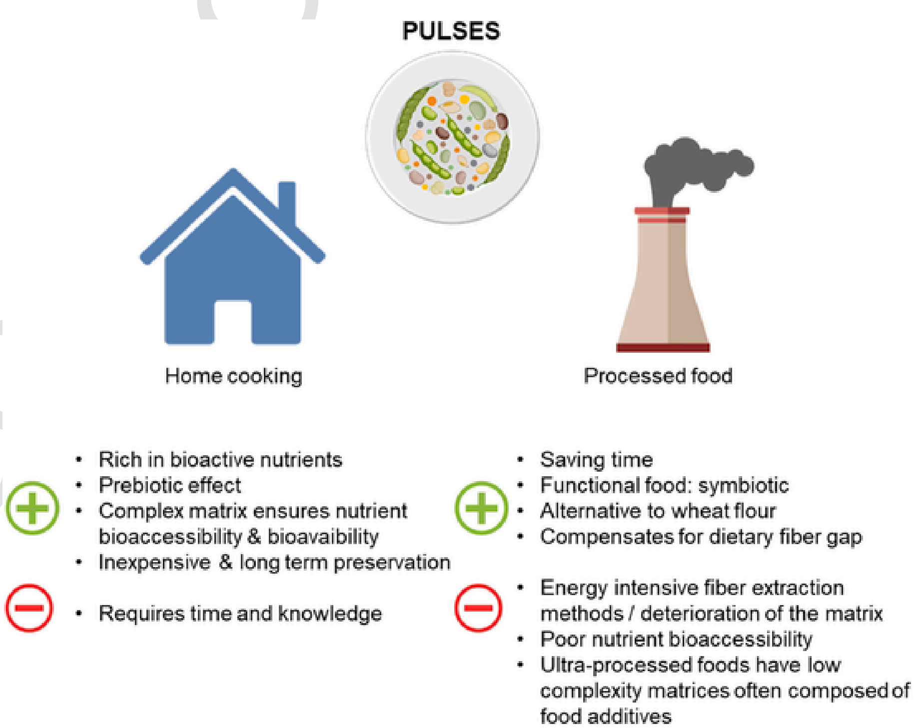

Fig. 2. Advantages and disadvantages of homemade *versus* Industrial foods in the consumption of pulses.
This figure summarizes the pros and cons of two methods of consuming pulse: homemade and industrial.

fied food ingredient that can provide a health benefit beyond the nutrients it contains' (Iwatani & Yamamoto, 2019). There are industrial products, which are enriched with pulse proteins or fibers to improve their nutritional value.

Pulse flours are increasingly being used to replace or mixed with cereal flours for industrial preparation (Bayomy & Alamri, 2022). Processed pulses and pulse-based foods can provide not only nutrient compounds but also significant amounts of bioactive compounds that may contribute to human health and well-being. These flour production processes tend to destroy the original food matrix, however, they can be used to make foods such as bread that will be denser and more compact, thus reducing the glycemic response (Bajka et al., 2021).

Prebiotics obtained from pulses has the potential to be effectively used in the production of functional health-based foods such as beverages, milk and yogurt (Sachin et al., 2022). While industrial producers often seek to reduce the proportion of α-galactooligosaccharides due to their anti-nutritional effects (Duraiswamy et al., 2023), resistant starch, on the other hand, possesses useful functional properties for the production of functional foods (Bozkır et al., 2023). This relies on the physico-chemical properties discussed above (water retention, viscosity, and gelatinization).

4.2.2.2. Highly processed foods. According to the NOVA (New classification), foods undergo different levels of processing, with the "ultra-processed" category being the most intensive. This group includes foods that have been enriched with components such as fiber, which are not naturally present in these foods but are added to enhance their health appeal (Monteiro et al., 2018).

To obtain isolated fibers from pulses, industrial processes must significantly deconstruct the food matrix (e.g. refining, extrusion, blowing). The natural foods that undergo extensive processing lose their original matrix cohesiveness and healthful potential, due to a weakened structural cohesion caused by the elimination of pre-existing interactions (Fardet, 2015). Furthermore, highly processed foods are often supplemented with excess free sugars, making the oligosaccharides more digestible and available in the bloodstream (Fardet & Rock, 2022). Globally, added micronutrients are not identical to the naturally occurring micronutrients in complex food matrices and therefore may not produce the same effects. In addition, several food additives present in these highly processed foods have adverse effects on the gut microbiota (Chassaing et al., 2022). Concurrently, there has been a hike in the availability of industrial substitutes for meat and dairy products made from plants in Western countries. Many of these substitutes are ultra-processed foods (UPF). The growth of this industrial market may have contributed to increased UPF consumption among vegetarian populations (Gehring et al., 2021). A cross-sectional study was conducted on 21,212 French individuals aimed to examine the role of UPF in different vegetarian diets (Gehring et al., 2021). They found that, compared to meat eaters, vegetarians and vegans in their sample consumed a higher proportion of their energy from UPFs, with many of the industrial plant-based meat and dairy substitutes created for these specific diets belonging to this food category (Gehring et al., 2021). While vegetarians and vegans showed a greater preference for healthy plant-based foods, there was also a higher frequency of individuals favoring unhealthy plant-based foods. Additionally, younger age at diet initiation and shorter duration of adherence to the diet were associated with greater consumption of UPFs (Gehring et al., 2021). Besides, the industrial processes required to produce pulse fibers are energy intensive. Among the water-soluble dietary fibers, α-GOS can be obtained from the seeds of pulses by extraction using a chromatographic method combined with chemical solvents (Lahuta et al., 2018). Extractable amounts vary between 1 and 10% depending on species and cultivar (Lahuta et al., 2018). On the other hand, there are methods of producing dietary fiber by enzymatic means, which are less energy-consuming. For example, α-GOS can be produced by α-galactosidase (α-Gal) transgalactosylation reactions or by the conversion of oligosaccharides of the raffinose family by levansucrase. However, there is very little data on α-Gal transgalactosylation reactions (Martins et al., 2019).

While food-labeling systems can guide consumers towards healthier food choices, they currently do not account for critical aspects such as the benefits of pulses for gut microbiota, the nature of dietary fibers in food ingredients, and the environmental impact of food production.

5. Discussion and future prospect

While health messages related to pulses are established by health authorities, it is noteworthy that none of the European nutritional recommendations, as highlighted in the study conducted by Hughes and collaborators, specifically emphasize the importance of maintaining a healthy gut microbiota (Hughes et al., 2022). Discussing the impact on gut health, it has been suggested that the microbiota component should be integrated into nutritional guidelines (Armet et al., 2022). Incorporating this aspect would not restructure the current dietary fiber guidelines; on the contrary, it would reinforce them, potentially advocating for even more robust recommendations (Delzenne et al., 2020). Transitioning to future perspectives, it is essential to recognize that dietary fibers are crucial for good health, and pulses, as a rich source of dietary fiber, represent an underexploited resource. Looking ahead, the development of a sophisticated metabolic model based on genomic and metagenomic data promises the potential to predict the interactions between complex dietary compounds and the human microbiota. Advancements in this area have already enabled predictions about the production of metabolites by the microbiota from lentils (Blasco et al., 2021), setting the stage for future research and application in dietary guidance.

Several studies have indicated that consumers perceive pulses as beneficial for their health, aligning with the information commonly conveyed by health authorities (Henn et al., 2022; Hughes et al., 2022; Melendrez-Ruiz et al., 2019). Considering the influence of health messages on European consumers, promoting a healthy gut microbiota could serve as a lever for increasing pulse consumption. Conversely, research has shown that consumers are misinformed about the environmental benefits of pulses (Henn et al., 2022). Pivoting to forward-looking initiatives, we propose drawing a parallel between the beneficial effects on the microbiota and the environment. Both the microbiota and the environment can be viewed as complex ecosystems that require balance for optimal health. Educating consumers about the positive effects on their intestinal microbiota might broaden their view to encompass environmental well-being. This expanded understanding could serve as a springboard for future educational campaigns. Advancing our discourse, by effectively communicating the dual benefits of pulses on the intestinal microbiota and the environment, we can aim to enrich the public's appreciation of pulses' role within broader ecosystem health. Hence, activating various communication strategies becomes crucial for initiating a shift in consumer behavior and advocating for both health and environmental stewardship.

The delicate balance between health benefits and environmental risks associated with pulse-based products is a crucial consideration. With the growing availability of processed pulse products in the market, it becomes essential to inform consumers on this matter, emphasizing that not all products confer equal health advantages. Transitioning to the perspective of regulatory impact, to safeguard the environmental integrity while promoting the beneficial effects of the intestinal microbiota, it is imperative to contemplate the incorporation of environmental criteria for all pulse-based foods seeking to benefit from health claims. Engaging in this dialogue could involve scientific associations and regulatory agencies, where the crux of the discussion would underscore the necessity to find a middle ground between the trade-off of health benefits and environmental risks. Looking to the future, evaluating the manufacturing processes of pulse-based foods and the sourcing of the pulses used (such as organic agriculture or by-products) could become a pivotal element in meeting these environmental criteria for health claims related to the microbiota. Moreover, with the wide diversity of products on the market—from those with high nutritional value to those laden with excessive fats and sugars contributing to the obesity, diabetes, and inflammatory bowel disease epidemics—it is clear that more discerning measures are needed. Projecting ahead, as some of these foods may receive health claims due to the prebiotic nature of pulses-derived nutrients in the coming years, we must be vigilant that such claims do not overshadow potential deleterious effects related to the overall composition of the end-product. It is, therefore, a call to action for industry and regulators alike to ensure that health claims are substantiated by holistic product assessments, not merely by the presence of beneficial nutrients.

In any strategy aimed at increasing the consumption of pulses, it is essential to consider the price and culinary skills required for their preparation. These factors play a significant role in shaping consumer choices and behaviors. Price is an important factor in food selection and is particularly important to low-income consumers. One study in France showed that these consumers considered the affordable price of pulse-based food products as a recognized advantage, but were less familiar with their nutritional value (Melendrez-Ruiz et al., 2019). Addressing the myriad external factors that shape food choices—ranging from personal taste to sociocultural influences—is a formidable challenge in designing effective public health policies. These policies must navigate complexities including price, accessibility, advertising, social contacts, sociocultural determinants, and local food environments (Dieteren et al., 2022). In this context, studies indicate a consumer preference for positive price-based interventions, such as bonuses or subsidies, over punitive measures like tax increases (Dieteren et al., 2022). Focusing on the future, for processed pulse products, which often come at a higher cost than raw pulses, it becomes crucial to identify promotion strategies that leverage pricing incentives. To balance the health and environmental implications, proposing tariff promotions for products that are bio-sourced, valorize co-products, and utilize energy-efficient processing methods may offer a novel approach. Such incentives could foster more sustainable consumer behaviors, aligning economic and environmental benefits with public health objectives.

Hartmann and collaborators elucidate the relationship between food choices and an individual's cooking abilities, underscoring the need for educational programs to enhance culinary skills as part of public health promotion efforts (Hartmann et al., 2013). This aligns with the concept that teaching people how to prepare nutritious meals can bridge the gap between nutritional guidelines and actual food practices, leading to more balanced diets. Looking ahead, integrating cooking classes into school curricula could be especially transformative for children and young adults, including those from low-income backgrounds who might not have access to reliable nutritional information (Eisenberg & Imamura, 2020). The benefits of such programs could be profound, equipping young people with the knowledge and skills to make healthier food choices from a young age. To extend this vision further, Eisenberg and collaborators propose the creation of culinary learning environments within educational and professional settings. These would be spaces dedicated not only to teaching the preparation of plant-based dishes but also to understanding plant culture and the principles of nutritious diets (Eisenberg & Imamura, 2020). The establishment of these environments would serve as incubators for lifelong healthy eating habits. By weaving culinary skill development into the fabric of our educational and professional institutions, we can anticipate a future where the norm is an informed approach to diet, emphasizing the role of nutritious, whole foods. This initiative could significantly contribute to the shift towards healthier dietary practices on a societal level.

Building on the imperative of enhancing cooking skills for improved diet quality, it is equally crucial to understand how preparation methods themselves can influence the nutritional value of the food we consume. The myriad ways in which legumes are processed and prepared, such as boiling, soaking, fermentation, and germination in home cooking, or their incorporation into diverse food matrices during industrial processing, significantly influence the bioavailability of dietary fibers (Thomson et al., 2021). These methods alter the physical and chemical properties of fibers, potentially affecting their fermentability by gut microbiota and consequent health outcomes. Given that legume consumption rarely occurs in isolation and is typically influenced by specific preparatory techniques, it is important to consider the fiber's functionality and its interaction within the gut ecosystem. With the current data being fragmentary, there is a critical need for more comprehensive research to improve our understanding of fiber availability and the impact of various preparation methods. Future studies should aim to elucidate how fibers transform during different culinary processes and how these changes influence the physiological benefits of fiber intake. Emphasizing these aspects carries implications for dietary recommendations and could shape public health initiatives, fostering a more nuanced approach to dietary guidance and the promotion of legumes as a functional food within a diverse and healthy diet.

6. Conclusion

Pulses stand out as a nutritional powerhouse with substantial environmental benefits, offering a viable strategy for enhancing the European agri-food system's sustainability. This review highlights the dual role of pulses: they serve as an excellent alternative to animal protein and play a pivotal role in fostering a healthy gut microbiota through their fiber richness. The clear message from the literature is that pulses should not be underestimated or overlooked in dietary guidelines. Consumers need to be informed about the wide-ranging benefits of pulses, from their contribution to gut health to their lower environmental footprint compared to animal-based proteins. Action from policymakers, educators, and the food industry is crucial to promote the consumption of pulses and help consumers distinguish between whole pulses and their ultra-processed counterparts. By elevating the profile of pulses in public health narratives, we can catalyze a dietary shift towards improved health outcomes and environmental sustainability. In conclusion, embracing pulses is a strategic move that supports both human health, via improved nutritional intake and gut microbiota, and the planet's well-being. Our synthesis of the literature underscores the need for pulses to take center stage in the European diet, a change that promises far-reaching benefits for all (Fig. 3).

Author contributions

Biscarrat Paul: Writing-Original draft preparation. Cherbuy Claire: Writing - reviewing and editing. Bedu-Ferrari Cassandre: Writing - reviewing and editing. Langella Philippe: Supervision.

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Declaration of competing interest

The authors declare no conflict of interest and no competing financial interest.

Data availability

No data was used for the research described in the article.

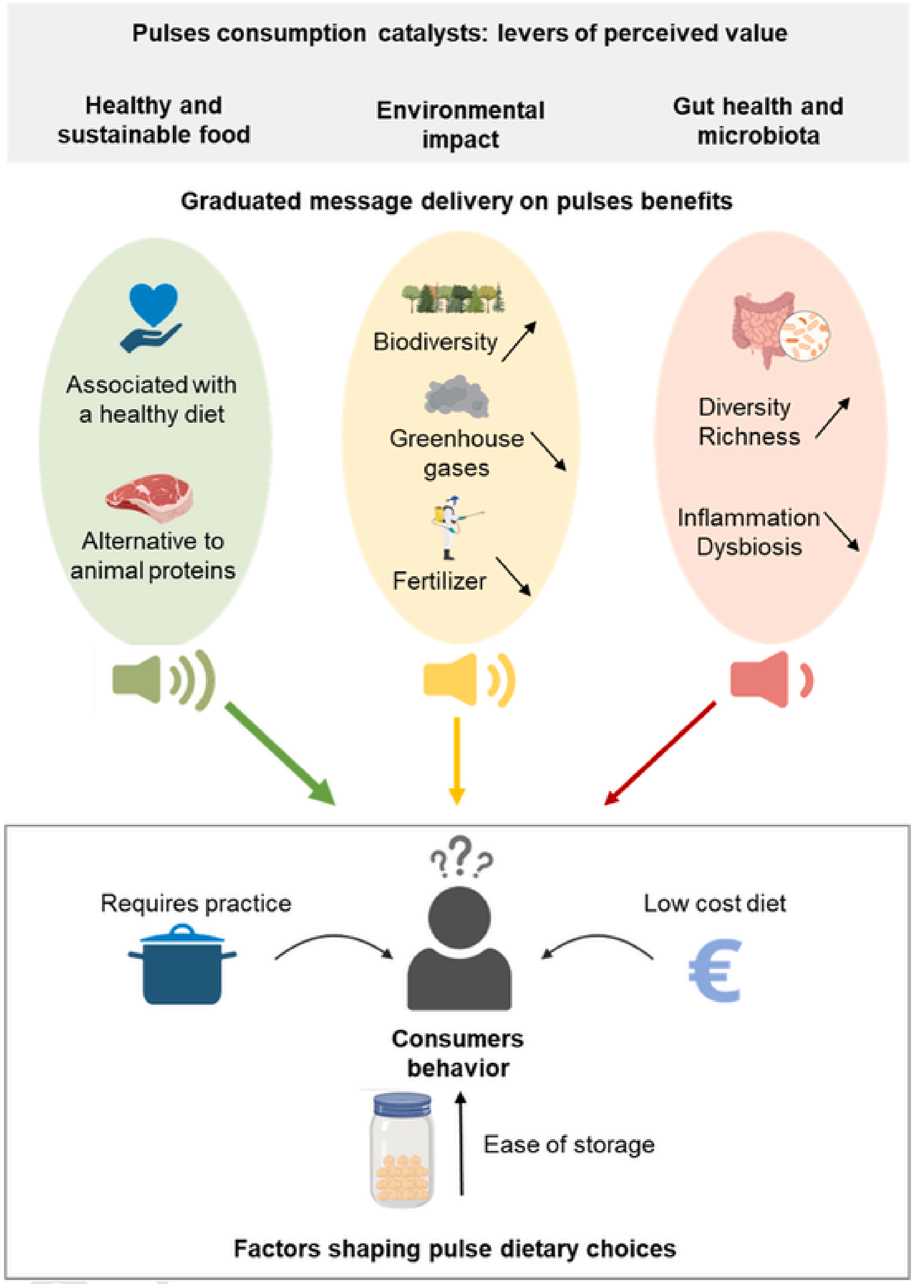

Fig. 3. Articulation of the different factors identified as having an impact on the perceived value of pulses.
The figure illustrates the information trajectory from source to consumer, delineating how messages about pulses' health and environmental benefits influence consumer behavior. The illustration captures three focal areas of communication: the well-understood health benefits of pulses as plant-based proteins, signified by a green loudspeaker; the moderately understood environmental advantages of pulse cultivation, denoted by a yellow loudspeaker; and the poorly recognized role of pulses in gut health via fiber content, indicated by a red loudspeaker. Despite the established perception, there remains an underexploitation of pulses as a pivotal source of dietary fiber, a point which could be leveraged to bolster fiber consumption. As these varied messages culminate at the consumer level, factors like affordability, storage convenience, and culinary knowledge shape consumption choices. This visualization advocates for strengthened communication strategies, underscoring the need to continue capitalizing on well-perceived messages while also enhancing consumer awareness of the underrepresented benefits of pulses for gut health. Doing so could serve as a key lever to increase dietary fiber intake, further integrating pulses into diets for comprehensive nutritional and environmental benefits. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

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Abbreviations

5-FTHF	5-formyltetrahydrofolate
5-MTHF	5-methyltetrahydrofolate
BA	Bile acid
BMI	Body Mass Index
CAZymes	Carbohydrate active enzymes
CVD	Cardiovascular diseases
CAP	Common Agricultural Policy
DP	Degree of Polymerization
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization of the United Nations
FBDG	food based dietary guidelines
FOS	Fructooligosaccharides
FuFoSE	Functional Food Science in Europe
GABA	Gamma-aminobutyric acid
GDD	Global Dietary Database
GLP-1	glucagon-like peptide-1
GOS	Galactooligosaccharides
GF	Gluten-Free
GHG	Greenhouse Gas
IBD	Inflammatory bowel diseases
IDF	Insoluble Dietary Fiber
ILSI	International Life Science Institute
ISAPP	International Scientific Association for Probiotics and Prebiotics
LDC	Low digestible Carbohydrate
LDL	Low-density lipoprotein
NO	Nitric oxide
N2O	Nitrous oxide
NSP	Non-starch polysaccharides
NDA	Nutrition, and Allergies
PUL	Polysaccharides Utilisation Loci
RFO	Raffinose Family Oligosaccharides
RS	Resistant Starch
SCFA	short-chain fatty acids
SDF	Soluble Dietary fiber
SA	Sugar Alcohols
T2B	Type II Diabetes
UPFs	Ultra-processed foods
WHO	World Health Organization
α-Gal	α-galactosidase

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