frontiers | Frontiers in Sustainable Food Systems

TYPE Review
PUBLISHED 30 October 2025
DOI 10.3389/fsufs.2025.1672634

OPEN ACCESS

EDITED BY
Prof Rajendra Kumar,
Indian Agricultural Research Institute (ICAR), India

REVIEWED BY
Santosh Kumar Gupta,
ICAR-Indian Institute of Millets Research (IIMR), India
Nandan Kumar,
Kansas State University, United States
Md Al-Mamun,
Bangladesh Jute Research Institute, Bangladesh

*CORRESPONDENCE
Claire Copperstone
✉ claire.copperstone@um.edu.mt

RECEIVED 24 July 2025
ACCEPTED 02 October 2025
PUBLISHED 30 October 2025

CITATION
Copperstone C, Jones P, Aydın B, Zivkovic J, Can Aytar E, Kalkan Yıldırım H, Ćujić Nikolic N, Künili İE, Yilmaz E, Tirpanci Sivri G, Seylam Küşümler A, Özalp Ünal D, Bratovcic A, Özmen Ö, Gunduz S, Šavikin K, Sirbu A, Rimac Brnčić S, Bantis F, Ivanova T, Chervenkov M, Orahovac A, Balazs B, Dilgen MN, Negrão S and Knez M (2025) Beyond hummus—an up-to-date scientific review of chickpeas, health, and environmental impact. *Front. Sustain. Food Syst.* 9:1672634.
doi: 10.3389/fsufs.2025.1672634

Beyond hummus—an up-to-date scientific review of chickpeas, health, and environmental impact

Claire Copperstone[1]*, Petra Jones[1], Betül Aydın[2], Jelena Zivkovic[3], Erdi Can Aytar[4], Hatice Kalkan Yıldırım[5], Nada Ćujić Nikolic[3], İbrahim Ender Künili[6], Ebru Yilmaz[7], Goksel Tirpanci Sivri[8], Aylin Seylam Küşümler[9], Derya Özalp Ünal[10], Amra Bratovcic[11], Özge Özmen[12], Selin Gunduz[10], Katarina Šavikin[3], Alexandrina Sirbu[13], Suzana Rimac Brnčić[14], Filippos Bantis[15], Teodora Ivanova[16], Mihail Chervenkov[16,17,18], Amil Orahovac[19], Balint Balazs[20], Mevlüde Nur Dilgen[2], Sónia Negrão[21] and Marija Knez[22]

[1]Department of Food Science, Nutrition and Dietetics, Faculty of Health Sciences University of Malta, Msida, Malta, [2]Department of Biology, Faculty of Science, Gazi University, Ankara, Türkiye, [3]Institute for Medicinal Plants Research "Dr. Josif Pančić", Belgrade, Serbia, [4]Department of Horticulture, Faculty of Agriculture, Usak University, Uşak, Türkiye, [5]Department of Food Engineering, Faculty of Engineering, Ege University, İzmir, Türkiye, [6]Faculty of Marine Sciences and Technology, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye, [7]Bozdoğan Vocational School, Aydın Adnan Menderes University, Aydın, Türkiye, [8]Food Engineering Department, Faculty of Agriculture, Tekirdag Namık Kemal University, Tekirdağ, Türkiye, [9]Department of Nutrition and Dietetics, Faculty of Health Sciences, Istanbul Okan University, İstanbul, Türkiye, [10]Institute of Field Crops Central Research, Ministry of Agriculture and Forestry, Ankara, Türkiye, [11]Department of Physical Chemistry and Electrochemistry, Faculty of Technology, University of Tuzla, Tuzla, Bosnia and Herzegovina, [12]Department of Food Engineering, Faculty of Engineering, Adana Alparslan Türkeş Science and Technology University, Adana, Türkiye, [13]FMMAE Ramnicu Valcea, Constantin Brancoveanu University of Pitesti, Ramnicu Valcea, Romania, [14]Faculty of Food Technology and Biotechnology, University of Zagreb, Zagreb, Croatia, [15]School of Agricultural Sciences, Department of Agriculture, University of Western Macedonia, Florina, Greece, [16]Department of Plant and Fungal Diversity and Resources, Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria, [17]Faculty of Veterinary Medicine, University of Forestry, Sofia, Bulgaria, [18]Department of Plant and Fungal Diversity and Resources, Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria, [19]Faculty of Food Technology, Food Safety and Ecology, University of Donja Gorica, Podgorica, Montenegro, [20]ESSRG Nonprofit Ltd., Budapest, Hungary, [21]School of Biology and Environmental Science, University College Dublin, Dublin, Ireland, [22]Centre of Research Excellence in Nutrition and Metabolism, Group for Nutrition and Metabolism, Institute for Medical Research, National Institute of Republic of Serbia, University of Belgrade, Belgrade, Serbia

Chickpeas (*Cicer arietinum* L.), form part of the pulses group and have been cultivated and consumed for many years, providing beneficial nutritional properties, whilst also being considered as sustainable foods. The global market for chickpeas is expected to continue growing because of increased consumer acceptability and growing needs for foods that support nutritional health and demand for alternative plant-based protein sources. Furthermore, these crops contribute to nitrogen fixation in soils and are therefore utilized for crop rotation systems, important in today's need to cope with sustainability demands. Food security is a major concern, with increasing pressure to supply affordable, accessible and nutritious foods to the world's growing population. On the other hand, challenges for chickpea consumption exist and may be in part explained by various sociocultural and economic factors, such as lack of knowledge and long preparation times, as well as the current global nutrition transition marked by increasing fast food availability and preferences. Crops like chickpeas therefore have an important role in addressing many Sustainable Development Goals (SDGs) including SDG 2 (Zero Hunger) and SDG 13 (Climate Action). Chickpeas' nutritional profile includes protein quality, fiber, micronutrients and bioactive compound content. Antinutrients are also present, reducing nutrient bioavailability and provoking digestive health issues with some allergenic potential also observed. Mitigation techniques range from pre-cooking methods such as soaking and dehulling, as well as various cooking processes and fermentation. The latter process has been shown to improve probiotic activity and reduce phytate levels, in particular. The aim of this review is therefore to re-examine the nutritional profile for the two main chickpea types, the 'kabuli' and 'desi' types, the limitations of the antinutritional factors present, and explore techniques to mitigate these compounds. Socio-cultural and economic limitations faced by farmers will be addressed, a concern since it could further exacerbate poverty and food insecurity. Successful strategies that have improved yields will also be presented. The review will therefore present the integration of nutritional health with environmental considerations so as to deliver an updated picture for the chickpea crop and provide actionable recommendations to address the growing global population's future needs.

KEYWORDS

chickpeas (*Cicer arietinum* L), nutrition and health, sustainability, underutilized crops, environmental conditions

1 Introduction

Chickpea (*C. arietinum* L.) is among the oldest and most widely consumed legumes globally. In the last five years, chickpeas ranked as the third most important pulse crop globally, following dry beans and peas according to the Food and Agricultural Organization of the United Nations (2025). Chickpeas, specifically, form part of the pulses group, the edible seeds of leguminous plants, and have been cultivated for their edible seeds for many thousands of years garnering interest as an important source of sustainable protein (Gundogan et al., 2024). The chickpea varieties are categorized according to their seeds into two types—'kabuli' with the thinner seed coat and creamy-white coloring and the thicker coat, darker colored, 'desi' type (Wood et al., 2011). While 'desi' chickpeas are predominantly produced in Africa and Asia, 'kabuli'; types are cultivated in Europe, North Africa, West Asia, and North America (Zhao et al., 2021). The global chickpea market is expected to grow rapidly through 2025, with this growth driven by the increasing demand for vegetable proteins as well as health and environmental concerns with diverse applications such as food and beverages, animal feed, amongst others. Chickpea production is carried out in more than thirty-three countries on approximately 17.3 million hectares of land worldwide (Food and Agricultural Organization of the United Nations, 2023).

The adaptability of this crop makes it a popular ingredient in many dishes, gaining popularity globally due to its presence in diverse dishes and cuisines (Wallace et al., 2016). Chickpeas are considered to be affordable sources of carbohydrate, valuable plant protein and dietary fiber. Their nutritional profile also includes the absence of cholesterol and the presence of important constituents such as unsaturated fats, vitamins, and minerals (Wallace et al., 2016; Gupta et al., 2017). Chickpea consumption is also considered for its positive health benefits including antioxidant and anti-inflammatory activities (Faridy et al., 2020). These properties make chickpeas a food that should be consumed by a wider audience and highlight the need to increase their global utilization and consumption.

Furthermore, global dietary transitions towards plant-based diet systems are increasingly recognized as effective strategies for mitigating environmental challenges whilst providing healthy diet options (Willett et al., 2019). Within this context, chickpeas emerge as versatile and sustainable agricultural commodities, demonstrating exceptional nutritional, ecological and economic potential. Although chickpeas are considered as one of the main 'founder' crops (Lev-Yadun et al., 2000), further information and research are required to promote their importance as a staple ingredient to encourage consumption of healthy and sustainable diets and support the global fight against malnutrition (Gangola et al., 2014). As the threats for climate change and global warming increase, coupled with more water shortages, there is an urgent need to address the availability of more sustainable crops, to mitigate these negative effects and improve food security.

The findings could therefore support the inclusion of chickpeas in national and international dietary guidelines, promoting greater consumer awareness and acceptance. Keeping this in mind, the primary aims of this review were to examine the existing evidence on the nutritional properties and health benefits of chickpeas, provide an updated overview of their environmental impact and sustainability considerations, and examine their role in public health policies. Research recommendations, based on current gaps, will also be proposed. Since the study did not include data collection from human participants, it did not require ethical review, so the study was submitted in self-declaration form at the Faculty of Health Sciences, University of Malta Research Ethics Committee (FREC) with the reference number: FHS-2025-00194.

2 Methodology

The authors have selected a narrative review style to search and also present their findings. A narrative review provides a succinct narration for the subject in context, includes practical information and is not confined to rigid inclusion and exclusion criteria (Sarkar and Bhatia, 2021). The authors considered the broadness and diversity of the selected aims of this review prior to presenting an easily readable and utilizable article in narrative review format.

A broad search strategy was utilized for the first sections using the databases: Google Scholar, Scopus, and Medline, covering nutritional aspects and antinutrients, utilizing key words that included: chickpeas OR '*cicer arietinum* L.' AND 'nutritional composition' OR micronutrient* OR macronutrient* OR vitamin* OR mineral* OR antioxidant* OR polyphenol* OR protein* OR carbohydrate* OR fiber* OR antinutrient* OR 'protease inhibitor*' OR phytate* OR oxalate* OR lectin* OR tannin* OR saponin* OR amylase* OR oligosaccharide* OR phytic acid* OR trypsin. The search was supplemented through hand searching to retrieve grey literature such as technical and policy reports and other relevant studies to achieve a more comprehensive perspective on chickpeas and provide a wider representation of the topic. Peer-reviewed articles and reports were included if they were published within the search period of 2000–2025. The broad search period sought to capture a comprehensive information base and to report on any changing trends through time.

3 Morpho-anatomical characteristics and nutritional composition of chickpeas

The chickpea crop is an annual herb, well-suited to mild, arid climates, exhibiting high tolerance to heat, when provided with sufficient moisture in the soil. However, large-seeded 'kabuli'-type varieties thrive best in temperate regions (Dida Bulbula and Urga, 2018; Sajja et al., 2017). These varieties are primarily consumed in the Mediterranean region. In the Americas, preferred varieties are large seeds (100–750 mg), round in shape, with a smooth surface and beige color. The varieties of 'desi'-types are primarily grown in semiarid regions. The seeds are smaller (80–350 mg), angular, with a rough, striated surface. Average energy content is 383 kcal/100 g (U.S. Department of Agriculture, 2023).

3.1 Macronutrient composition

Table 1 depicts a summary of the main macronutrients in chickpeas as shown in the USDA (U.S. Department of Agriculture, 2023) Food Data Central database. The next sections will discuss variabilities in composition due to factors such as crop type and processing methods.

3.1.1 Protein content and amino acid profile of chickpeas

Overall, the chickpea seeds contain protein values comparable to other legumes, such as the common bean and soybean (Chang et al., 2012). Variability in protein composition and content is influenced by factors such as type, variety geolocation, environmental conditions, growing season, and analytical methods (Zia-Ul-Haq et al., 2007). Chickpeas are a good source of protein, with reported values generally 21.3 g/100 g for dry chickpeas (U.S. Department of Agriculture, 2023). Different varieties however exhibit varying content, for example the 'desi' line was reported to have a high protein content of 29.2 g/100 g, higher than that of the 'kabuli' type, reported at 20.2 g/100 g (Gaur et al., 2016).

Variations in protein content also occur after cooking, for example Wang et al. (2010b) detail increases in protein content from 22.9 to 23.7 g/100 g for 'desi' and 21.3 to 22.6 g/100 g for 'kabuli' types after cooking the chickpeas in water. The general protein quality of chickpeas is considered superior to that of other pulses. *In-vitro* digestibility for the 'kabuli' type was reported to be higher than that of the 'desi" type at 87.47 and 80.82%, respectively, (Wang et al., 2010a) in one experimental study on Chinese cultivars. The same study also concluded that the amino acid score for essential amino acids was adequately attained on both cultivar types. However the sulfur containing amino acids, were the most limiting, also reported in another study testing four 'desi' chickpea cultivars grown in Pakistan, where methionine and cystine were found mostly in limiting amounts (Zia-Ul-Haq et al., 2007). Chickpeas, overall, remain an important source of dietary protein and calories and with higher protein bioavailability than other legumes, so could be considered as good protein sources. Protein deficiencies can therefore be addressed by supplementing cereals with legumes like chickpea, particularly in Asian countries where cereals constitute the basis of the population diet (Zia-Ul-Haq et al., 2007).

3.1.2 Carbohydrate composition of chickpeas

Carbohydrates represent the most abundant macronutrient in chickpeas with approximate levels of 60.4 g/100 g (U.S. Department of Agriculture, 2023) and a total dietary fiber content of 12.2 g/100 g (U.S. Department of Agriculture, 2018). Most of this fiber (approximately 75.0–96.0%,) is of the insoluble type. 'Desi' chickpeas contain higher total and insoluble dietary fiber content compared to 'kabuli' types due to their thicker husks, but soluble dietary fiber content is similar for both types. Processing also affects the carbohydrate content and digestibility although this varies according to type of product and the process being utilized. In chickpea seeds sourced from Spain, soaking and cooking improved starch availability by 20% (Aguilera et al., 2009). Chickpeas also contain a high oligosaccharide content, in the form of raffinose, also affected by processing. Dehydration after soaking and cooking, in fact caused a significant reduction, by 57%, in chickpeas (Aguilera et al., 2009).

TABLE 1 Macronutrient composition for dry chickpeas (U.S. Department of Agriculture, 2023).

Macronutrient	Content/100 g	Derived	DRVs*
Energy (Atwater general factors)/Atwater specific factors	383 kcal/372 kcal	Calculated	2,200 kcal (AR)
Protein	21.3 g	Calculated	58.1 g (PRI)
Lipid/Fat	6.3 g	Analytical	49–86 g (RI)
Carbohydrates	60.4 g	Calculated (by difference)	248–330 g (RI)

DRVs, Dietary Reference Values; PRI, Population Reference Intake; RI, Reference intake; AR, Average requirement.
*DRVs based on adult 50-year old male weighing 70 kg (European Food Safety Authority, 2019).

3.1.3 Fat content and composition of chickpeas

Chickpeas have a low fat content, at 6.27% (U.S. Department of Agriculture, 2023). However, there is a range of fat content found in different cultivars. In a study quantifying fatty acid composition on a variety of cooked pulses (boiling), which included four varieties of Canadian cultivars, an oil yield of 8.39 ± 0.03 g/100 g was reported (Padhi et al., 2017). Another study analyzing Chinese cultivars confirmed a range of lipid content between 6.35 ± 1.65 g/100 g and 9.35 ± 2.00 g/100 g and with high oleic and linoleic acids prevalent in both 'kabuli' and 'desi' types (Xiao et al., 2022). An experimental study on 'desi' chickpea cultivars grown in Pakistan revealed that the seeds were a good source of the essential fatty acids, linoleic and linolenic acids, and also contained the unsaturated fatty acid, palmitic acid (Zia-Ul-Haq et al., 2007).

3.2 Micronutrient composition

Chickpeas are a valuable source of essential micronutrients: minerals and vitamins, contributing significantly to human nutrition. Micronutrient composition (average values for dry chickpeas per 100 g of product) derived from seven European countries (Finland, France, Germany, Italy, Netherlands, Sweden, United Kingdom), obtained from the database of European Food Safety Authority (2021) are summarized in Table 2. For folate and beta-carotene, French Food Composition Tables are utilized (Ciqual-Anses, 2020). However, when looking at data from primary studies, different varieties of 'kabuli' and 'desi' exhibit varying micronutrient content, with wide ranges observed. In an experimental study comparing nutritional values in different varieties of Indian chickpea, and including two local varieties of chickpeas, this study reported small, but significant differences, in calcium content (range: 127.50 ± 0.09–183.86 ± 0.22 mg/100 mg), with values reportedly lowest and also highest in 'desi' varieties (Mathew and Shakappa, 2024). Vitamin A precursors, such as β-carotene, lutein, and zeaxanthin, also vary significantly across cultivars with β-carotene levels reaching 0.104 mg/100 g. This was concluded in a study where 'desi' chickpea accessions were reported to have a higher carotene content than 'kabuli' chickpeas (Ashokkumar et al., 2015). Folate content also varies greatly, with contents ranging from 42–589 μg/100 g (Jha et al., 2015).

Cooking also has an effect on micronutrient content. This varies according to the chickpea type. Wang et al. (2010b) report significant mineral content changes for zinc for 'desi', but not 'kabuli' varieties (4.07 to 4.56 mg/100 g and 3.4 to 3.48 mg/100 g respectively) and significantly reduced values for magnesium for 'kabuli' (147.0 to 132.3 mg/100 g) but not 'desi' chickpeas (169.0 to 157.0 mg/100 g) after cooking.

TABLE 2 Micronutrient composition of chickpeas compared with EFSA DRVs.

Micronutrient	Content (/100 g raw)	DRVs (Male Adults)	Nutritional relevance	Database References
Iron (Fe)	6.44 mg	11 mg/d (PRI)	Important for oxygen transport, electron transfer, oxidase activities and energy metabolism	European Food Safety Authority (2021)
Zinc (Zn)	2.27 mg	9.4–16.3 mg/d with 300-1200 mg/d phytate (PRI)	Cofactor for >300 enzymes; mitigated phytate improves Zn bioavailability	European Food Safety Authority (2021)
Magnesium (Mg)	150 mg	350 mg/d (AI)	Supports bone mineralization and muscle function	European Food Safety Authority (2021)
Calcium (Ca)	131.71 mg	1,000-950 mg/d (PRI)	Essential for bone metabolism; bioavailability influenced by phytate	European Food Safety Authority (2021)
Vitamin B1 (Thiamine)	0.45 mg	0.1 mg/MJ/d (PRI)	Energy metabolism, nerve function	European Food Safety Authority (2021)
Vitamin B2 (Riboflavin)	0.17 mg	1.6 mg/d (PRI)	Redox reactions, antioxidant defense	European Food Safety Authority (2021)
Vitamin B3 (Niacin)	4.59 NE mg	1.6 mg NE***/MJ/d (PRI)	NAD/NADP cofactor; energy metabolism	European Food Safety Authority (2021)
Vitamin B6 (Pyridoxine)	0.49 mg	1.7 mg/d (PRI)	Amino acid metabolism, neurotransmitter synthesis	European Food Safety Authority (2021)
Vitamin E (α-,tocopherol)	3.10 mg	13 mg/d (AI)	Antioxidant, protects cell membranes	European Food Safety Authority (2021)
Folate	369 μg	330 μg/DFE**/d (PRI)	Critical for DNA synthesis and cell division	Ciqual-Anses (2020)
β-Carotene (provitamin A)	40 μg	750 μg RE****/d (PRI) -Vitamin A	Precursor of vitamin A, vision and immune health	Ciqual-Anses (2020)

*DRVs, Dietary Reference Values; **DFE, Dietary Folate Equivalent. ***NE, Niacin Equivalent. ****RE, Retinol Equivalent where 1 μg RE, 1 μg retinol, 6 μg β-carotene and 12 μg other provitamin A carotenoids; PRI, Population Reference Intake; AI, Adequate Intake as defined by the European Food Safety Authority (2019).

3.3 Antinutrients, toxins and their mitigation

Chickpeas also contain antinutrients that limit digestibility and reduce nutritional value. Oligosaccharides, such as raffinose and stachyose, are one primary example of antinutritional factors which contribute to intestinal discomfort and bloating. Some polyphenolic compounds, which are present in higher levels in dark-coated chickpeas, also bind minerals and reduce their gastrointestinal absorption causing deficiencies such as anemia, however these effects are not always consistent and can depend on the individual's personal factors or different processing methods. Phytolectins, a structurally complex class of sugar-binding glycoproteins from legumes, have been shown to interact with glycoprotein on the surface of erythrocytes, resisting digestion. Saponins display inhibitory digestive enzyme activity, causing issues with digestive health and reduced nutrient absorption and utilization (Samtiya et al., 2020). Beneficial effects are also noted, through the reduction of lipid and cholesterol. While chickpea allergy prevalence is lower than peanut/soy, IgE-mediated cross-reactivity with other legumes (lentil/pea) are documented (Abu Risha et al., 2024; Mastrorilli et al., 2024). Additionally, chickpea allergens share structural homology with lentil and pea proteins, increasing the chance of cross-sensitization (Abu Risha et al., 2024).

A counter argument is that these antinutrients also contribute to beneficial health, with many antinutrients also considered as bioactive compounds. Therefore, consumers need to be informed of ways to reduce their negative effects whilst maximizing their beneficial properties through processing and portion control. Processing techniques can reduce antinutrient levels and allergenic potential and therefore mitigate their effects, whilst enhancing the flavors and palatability. Examples include pre-cooking techniques such as dehulling and soaking. Soaking dissolves and removes some antinutritional compounds through the discarded water, while metabolic changes during soaking also affect the seed content. In fact, soaking chickpea seeds has been reported to significantly decrease the lectin, total and soluble oxalate content (Shi et al., 2018). Soaking and germination also lowered phytate and tannin content with shorter cooking times required, with germination activating endogenous phytase, thus degrading phytate, whilst also increasing iron and zinc bioavailability (Haileslassie et al., 2019). This process also softens seeds, making them easier to cook, and dissolves other undesirable substances. Furthermore, soaked seeds retain moisture, although additional heat treatment is needed for stabilization and flavor improvement (Zhou et al., 2024; Fuso et al., 2025).

Techniques such as autoclaving, heating, microwave cooking, boiling, extrusion, fermentation, irradiation, and enzymatic treatments, are also effective in reducing or neutralizing antinutrients, making chickpeas more bioavailable and nutritionally robust with some specific examples tackled next. Traditional cooking methods such as roasting and boiling improve the utilizable carbohydrate content and overall nutritional quality (Dida Bulbula and Urga, 2018). Heat treatment was shown to reduce oligosaccharides from 5.2 to 3.2 g/kg dry matter for 'desi' and from 7.2 to 4.2 g/kg in 'kabuli' chickpeas. Similarly, heating caused reduction in trypsin inhibitor activity (TIA) from 8.29 to 0.75 g/kg and 6.41 to 1.31 g/kg for 'desi' and 'kabuli' chickpeas, respectively, (Wang et al., 2010b). In presoaked batches, autoclaving (15 lb. pressure at 121 °C) was highly effective in reducing TIA by 83.67% whereas boiling at 100 °C for 90 min reduced TIA by 82.27% (El-Adawy, 2002). Microwave cooking, in particular, reportedly protected against losses of the thermolabile B vitamins (Alajaji and El-Adawy, 2006).

Extrusion cooking benefits include gelatinization of starch, enhancement of soluble dietary fiber content, reduction of lipid oxidation, and maintenance of natural food colors and flavors (Ciudad-Mulero et al., 2022). This technique also reduces antinutrients, like lectins, tannins, inositol hexaphosphate and enzyme (trypsin, chymotrypsin and α-amylase) inhibitors from different legume seeds (Singh et al., 2017). This process therefore increases the bioavailability of minerals, supporting bone health, and improving overall nutritional status. The process also increases the antioxidant capacity of chickpeas, contributing to the fight against free radicals and potentially reducing the risk of cardiovascular disease. Extrusion increases protein digestibility, allowing their effective use (Chávez-Ontiveros et al., 2022). Furthermore, extrusion positively impacts the gut microbiota, further supporting gut health and regulation of the digestive system (Ajay et al., 2024). Autoclaving is also effective in reducing phytic acid content: temperatures of 121 °C for 15 min were found to lower phytic acid content significantly (1806.25 ± 0.88 to 1315.63 ± 0.13 mg/100g) and also improved mineral digestibility (Bektaş and Ertop, 2021).

Fermentation is an alternative technological process that enhances the nutritional quality and produces edible products with improved sensory properties. This processing method was shown to maintain the chickpea protein content while simultaneously reducing the levels of lipids and ash (Reyes-Moreno et al., 2004). Fermentation also improves intestinal flora by increasing the activity of probiotic microorganisms, regulating the digestive system and strengthening immune function. It also improves bone health and overall nutritional status by increasing the bioavailability of minerals through the reduction of antinutritional factors. In fact, fermentation of chickpeas, and other leguminous foods, can decrease phytic acid activity by activating endogenous phytases and reducing gastrointestinal pH (Tamang et al., 2025). Among emerging options, high-pressure treatment of chickpeas was shown to accelerate hydration and reduce tannins to approximately 25 mg CE/100 g and phytate to approximately 0.20% while improving texture and color, requiring less soaking time to produce safe, digestible chickpeas before cooking (Alsalman and Ramaswamy, 2020). A summary of the positive effects of the more commonly utilized mitigation techniques is provided in Table 3.

Processing methods such as glycation/fermentation and enzymatic hydrolysis can also modulate allergenicity at the protein level and may lower IgE reactivity, although this does not guarantee safety for sensitized individuals (Gupta et al., 2017). Therefore, clear allergen labeling, clinical awareness, and risk communication can protect sensitive consumers. Development of extruded hypoallergenic protein isolates is an emerging area with potential to further ensure even safer and economical consumption of plant-based foods.

Toxic elements including aluminium, arsenic, cadmium, mercury, and lead were analyzed from samples obtained from a South Korean market. Estimated chickpea weekly intakes were compared to the levels found in chickpea samples and found to be lower than 1% for most of the elements. Furthermore, the total hazard quotient (THQ) and total hazard index (HI) were calculated to be below the value of 1 (Gu et al., 2021). Fungal and mycotoxin contamination which can occur in chickpea and its products (such as chickpea flour), can be mitigated through cooking and through proper storage conditions. The authors of

TABLE 3 Processing techniques and their beneficial effects.

Process	Beneficial effects	References
Soaking/germination	Retains moisture Softens seeds Dissolves antinutrients eg phytate, tannins, lectin and oxalate Shortens cooking times Increase zinc/iron bioavailability	Fuso et al. (2025); Haileslassie et al. (2019); Shi et al. (2018); Zhou et al. (2024)
Dehulling	Improved starch digestibility Improved mineral bioavailability	Oghbaei and Prakash (2020)
Cooking(heat treatment)	Improved utilizable carbohydrate and protein content Reduced antinutrients such as raffinose and reduced trypsin inhibitor activity	Dida Bulbula and Urga (2018); Wang et al. (2010b); El-Adawy (2002)
Extrusion cooking	Maintains food color Enhances soluble fiber content Increases protein digestibility Reduces lectin, tannins, enzyme inhibitors etc. Improves starch gelatinization Reduces lipid oxidation Increases mineral bioavailability Improves gut microbiota	Ajay et al. (2024); Chávez-Ontiveros et al. (2022); Ciudad-Mulero et al. (2022); Singh et al. (2017)
Microwave cooking	Lowers losses in B vitamins	Alajaji and El-Adawy (2006)
High pressure processing	Reduces tannins and phytate Improves digestibility	Alsalman and Ramaswamy (2020)
Fermentation	Maintains protein content Improves intestinal flora Improves digestion and probiotic activity Increases mineral bioavailability Decreases antinutrient activity for e.g., phytates Strengthens immune function Modulates allergenic potential	Gupta et al. (2017); Reyes-Moreno et al. (2004); Tamang et al. (2025)

this review concluded that more studies are required on the subject of mycotoxins and their possible effects (Ramirez et al., 2018).

Tolerance levels are good, for example in a double -blind, placebo controlled, cross-over trial studying gastrointestinal symptoms after consumption of soaked and cooked (for 60 min) chickpeas and other pulses, compared to a potato control, found that participants overall only had mild symptoms (Veenstra et al., 2010). Consumers need to be guided on distinguishing between the information available on raw and cooked equivalents, since the values of antinutrients are greatly decreased in the cooked counterparts.

4 Health benefits of chickpeas

4.1 Bioactive compounds in chickpeas

Chickpeas demonstrate significant genetic diversity, considered a crucial consideration when developing cultivars rich in bioactive compounds. These compounds include polyphenols, flavonoids (flavanols, flavones, flavanones), anthocyanins, tannins, saponins and bioactive peptides such as albumin, globulin, and defensin, which collectively present significant potential for contributing to human health and well-being (Serventi and Dsouza, 2020). Specific implications for non-communicable (NCD) disease prevention such as diabetes, cardiovascular disease, cancer, digestive health and weight management are discussed in the following sections. See Table 4.

Polyphenols, are one example of bioactive compounds, mainly concentrated in seed coats (Segev et al., 2010), and exhibiting strong antioxidant properties thus playing a crucial role in protecting cells from oxidative damage. Darker chickpeas overall possess higher concentrations of these beneficial compounds when compared to lighter-colored varieties (Timoracká et al., 2022; Heiras-Palazuelos et al., 2013) including elevated levels of total polyphenol content, total flavonoid content and antioxidant activity. The saponins present in the colored 'desi' chickpeas possess antiproliferative effects which are retained after soaking (Milán-Noris et al., 2023).

4.2 Diabetes prevention and weight management

Pulses, such as chickpeas, are considered to have a low glycemic index (GI), such that regular consumption leads to lower fasting glucose

TABLE 4 Bioactive compounds in chickpeas and their associated health effects.

Bioactive compound	Main forms/examples	Health effects (focus: cancer prevention)	References
Flavonoids, other phenolic compounds	Phenolic acids, flavones; isoflavones (phytoestrogens)	Antioxidant; reduce DNA damage; induce apoptosis; lower risk of post-menopausal breast cancer	de Camargo et al. (2019); Sehar et al. (2023); Heiras-Palazuelos et al. (2013); Luna-Vital and de Mejía (2018); Segev et al. (2010); Wu et al. (2008)
Saponins	Dioscin, aglycone, avicin, soyasaponins; ginsenosides	Disrupt membranes; induce apoptosis; anti-inflammatory; cell cycle arrest; antiproliferative effects; suppress tumor angiogenesis	Man et al. (2010); Milán-Noris et al. (2023); Singh and Basu (2012)
Bioactive peptides	Albumins, globulins, defensins; enzymatic hydrolysates/peptides; fermented chickpea peptides	Antioxidant/anti-inflammatory; varying anti-gastrointestinal cancer mechanisms including apoptosis interaction/disruption of mitochondrial membranes	Luna-Vital and de Mejía (2018); Real Hernandez and Gonzalez de Mejia (2019); Sehar et al. (2023)
Lectins	Chickpea lectin	Anti-proliferative effects; induce apoptosis	Gupta et al. (2018)
Oligosaccharides	Raffinose, ciceritol	Fermentation releases SCFAs which increase microbiota modulation, improves colonic transit providing colorectal cancer protection	Carretta et al. (2021); Salvi and Cowles (2021)

levels and improved glycated hemoglobin. This is primarily due to the chickpeas' high fiber and resistant starch content, all of which reduce carbohydrate digestion (Dhillon et al., 2016; Vélez et al., 2023). Additionally, chickpea-derived peptides may enhance insulin sensitivity, supporting their role in managing Type 2 diabetes mellitus (Aisa et al., 2019). The resistant starches in chickpeas improve gut microbiota composition, fostering a balanced microbiome that supports metabolic health and lowers the risk of metabolic syndrome (Ajay et al., 2024).

The protein in chickpeas also stimulates the release of Peptide YY and Glucagon-Like-Peptide-1, reducing hunger and promoting a feeling of fullness, potentially reducing caloric intake. The fiber content, particularly soluble fiber, also enhances satiety by slowing gastric emptying and stabilizing blood glucose levels, thereby mitigating postprandial insulin spikes associated with fat storage (Zafar and Kabir, 2017). Incorporating chickpeas into a calorie-controlled diet is therefore potentially associated with reductions in body weight supporting weight loss and obesity prevention and management in the longer term.

4.3 Cardiovascular health and cancer prevention

Chickpeas significantly reduce inflammation by suppressing pro-inflammatory cytokines like interleukin-6, tumor necrosis factor-alpha and C-reactive protein. Additionally, consuming chickpea protein hydrolysates reduces systemic inflammation, suggesting they may serve as a potential therapeutic tool for inflammatory conditions (Faridy et al., 2020). By diminishing systemic inflammation, chickpeas can help lower the risk of endothelial dysfunction, a significant factor in cardiovascular conditions (Roy et al., 2010). Chickpea-derived bioactive peptides have also been reported to modulate inflammation by enhancing the activity of antioxidant enzymes (Mahbub et al., 2021). These compounds help to neutralize harmful free radicals, thereby reducing the risk of chronic diseases (Singh et al., 2017; Xue et al., 2015) such as cardiovascular health. Furthermore, they enhance the absorption of essential minerals and vitamins. The polyphenols found in chickpeas, such as quercetin and kaempferol, further contribute to the anti-inflammatory effects by neutralizing reactive oxygen species and reducing oxidative stress, a precursor to inflammation (de Camargo et al., 2019).

A legume-based, hypocaloric diet was reported to significantly lower cholesterol levels, compared to a non-legume control diet, likely due to the inhibition of hepatic fatty acid synthesis by fiber fermentation products (Crujeiras et al., 2007). Results overall demonstrated that consuming chickpeas reduced cholesterol levels and improved insulin resistance. Zhang et al. reported that the ciceritol in chickpeas promoted beneficial bacteria growth, inhibited harmful ones, and increased short-chain fatty acid production (SCFA), suggesting its prebiotic potential (Zhang et al., 2017). Sprouted chickpeas have been found to possess higher anti-inflammatory potential compared to cooked chickpeas, owing to the synergistic effects of peptides and phenolic compounds (Milán-Noris et al., 2018).

Recent studies on chickpeas also provide evidence for their role in mitigating cancer risk (Sehar et al., 2023). Their effectiveness stems from multiple mechanisms, including antioxidant activity, gut health modulation, and tumorigenesis inhibition. The carbohydrates and oligosaccharides undergo microbial fermentation in the colon, leading to the production of SCFA. These SCFA have anti-inflammatory properties which are associated with reduced colorectal cancer and inflammatory bowel disease risks (Carretta et al., 2021). Butyrate, in particular, serves as the preferred energy source for colonocytes and modulates intestinal inflammation (Salvi and Cowles, 2021). Daily consumption of chickpeas improves fecal butyrate levels and generates more frequent bowel movements, suggesting improved colonic transit and overall gut function. These effects are attributed not only to the bulking action of the insoluble fiber, which accelerates intestinal transit and reduces constipation risk, but also to a favorable gut microbiota composition. Large-scale meta-analyses further reinforce this evidence base, reporting that consumption of higher amounts of legumes is consistently associated with lower colorectal cancer risk (Schwingshackl et al., 2018).

Traditional crops like chickpeas can be utilized to improve human health by targeting specific physiological pathways generally involved in cancer development (Bar-El Dadon et al., 2017). The antioxidant properties of chickpeas can prevent DNA damage, lipid peroxidation, and protein oxidation, processes, which all implicated in cancer development. Sehar and colleagues demonstrated that chickpea polyphenols significantly reduced reactive oxygen species levels in cancer models, highlighting their potential to mitigate oxidative stress-related tumor development (Sehar et al., 2023).

In addition to polyphenols, chickpeas are also rich in saponins, which have drawn attention for their promising and diverse anticancer potential due to the wide variety of chemical structures they possess, with about 150 plant families reported to contain saponins (Man et al., 2010). A summary of these effects is shown in Table 4. Saponins exhibit strong anti-tumor activity by inducing apoptosis and inhibiting the proliferation of colon cancer cells as well as possessing anti-inflammatory properties. Singh and Basu reported that chickpea-derived saponins reduced tumor cell viability by disrupting cell membranes and interfering with signaling pathways critical for cancer progression. In addition to their direct anti-cancer effects, chickpeas contribute to cancer prevention through their rich micronutrient content (Singh and Basu, 2012). These include bioactive peptides, which are short-chain proteins produced during the enzymatic hydrolysis of chickpea proteins. These peptides exhibit properties such as antimicrobial and anti-inflammatory effects and have been shown to work against a range of gastrointestinal cancer mechanisms due to their interactions at cellular level (Real Hernandez and Gonzalez de Mejia, 2019; Sehar et al., 2023).

In the specific case of breast cancer, epidemiological studies have shown that women with higher legume and isoflavone intakes, especially in Asian populations, tended to have a lower risk of developing breast cancer during post menopause. This protective effect has been attributed mainly to the ability of isoflavones to act as weak estrogens and to modulate hormone-related pathways. Chickpea-derived compounds, though less extensively studied than soy, appear to work through similar mechanisms by providing phytoestrogens and other bioactive molecules that influence cell growth and apoptosis (Luna-Vital and de Mejía, 2018). Meta-analyses have strengthened this view by reporting that women consuming higher levels of isoflavones had lower recurrence rates and better long-term outcomes, particularly in estrogen receptor–positive cases (Wu et al., 2008).

4.4 Digestive health

The gut microbiota is increasingly recognized as a central regulator of digestive and systemic health. The bioactive compounds present in chickpeas may contribute to gut health by attenuating inflammation and oxidative stress within the intestinal mucosa (Nicolás-García et al., 2021). These compounds can modulate nuclear factor kappa-light-chain-enhancer of activated B cells and mitogen-activated protein kinase signaling pathways, thereby reducing pro-inflammatory cytokine expression in gut epithelial cells (Behl et al., 2022; Kim et al., 2009). Chickpeas also support digestive health by promoting beneficial gut bacteria such as *Bifidobacterium* and *Lactobacillus*, which are linked to enhanced barrier function and reduced intestinal permeability (Ajay et al., 2024). Their prebiotic-like oligosaccharides likely drive these effects, though outcomes may vary by individual microbiota composition. An experimental study carried out (Uriot et al., 2025) further showed that probiotics produced from chickpeas and algae improved microbiota composition, a marker of gut resilience and protection against inflammatory conditions like inflammatory bowel disease and ulcerative colitis. However, in sensitive individuals, the same oligosaccharides may cause bloating or discomfort particularly when chickpeas are not properly prepared (Elango et al., 2022).

Chickpeas therefore contribute to digestive health through a multifactorial network of mechanisms ranging from microbial fermentation and SCFA production to gut barrier reinforcement and anti-inflammatory signaling. While these effects are broadly beneficial, individual variability in microbiome composition and fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAPs) sensitivity may change outcomes. Chickpeas can be therefore recognized as both a nutritive food and a functional prebiotic agent in the context of digestive wellness, with their greatest benefits realized in personalized or population-tailored dietary strategies.

4.5 Bone health

Chickpea is a valuable source of minerals essential for maintaining bone health. Calcium plays a crucial role in bone metabolism by interacting with the calcium-sensing receptors which regulate bone cell activity. This interaction supports critical processes such as pre-osteoblast proliferation, differentiation into osteoblasts, and bone matrix protein mineralization (Brown, 2013).

Phosphorus, another key mineral present in chickpeas, contributes to hydroxyapatite, the primary inorganic component of bone. It is essential for forming phospholipids, phosphoproteins, and ATP, all of which play integral roles in bone metabolism (Serna and Bergwitz, 2020). However, maintaining a balanced calcium-to-phosphorus ratio is critical, as excessive phosphorus intake relative to calcium can impair bone mineralization.

Emerging *in-vitro* studies highlight chickpeas' potential to positively influence bone health. Combination of Vitamin D with chickpea protein hydrolysates was reported to show therapeutic potential through its antioxidant and anti-inflammatory properties (Alcalá-Santiago et al., 2024).

Despite their high mineral content, chickpeas contain phytic acid, as mentioned earlier, which can reduce mineral bioavailability. Nevertheless, recent evidence challenges the traditional view of phytic acid as only possessing antinutrient properties. Studies now indicate that it could support bone development by enhancing the osteogenic differentiation of mesenchymal stem cells, mitigating oxidative stress through circular RNA-mediated pathways. In human populations, positive associations with bone mineral density and reduced fracture risk were reported (Tamang et al., 2025).

Human trials also corroborate the link between the consumption of chickpeas and bone health. A pilot open-label trial involving fifty patients with knee osteoarthritis demonstrated that daily consumption of chickpea broth for 30 days significantly reduced pain, improved functional outcomes, and enhanced overall quality of life. High compliance and minimal side effects were also reported (Ahmadi et al., 2020). This direct clinical evidence linking chickpea intake with musculoskeletal health improvements suggests their potential role in managing bone- and joint-related conditions.

5 Sustainability considerations and chickpeas

5.1 The contribution of chickpeas towards the Sustainable Development Goals (SDGs)

Malnutrition, in the form of undernutrition, is widespread, particularly in low- and middle-income countries and causes significant increases in the burden of death and disease (Bar-El Dadon et al., 2017). A recent report on the state of food security and nutrition, informs on progress achieved, particularly on SDG 2, Zero Hunger, and discusses the negative impacts of the pandemic and the subsequent lack of progress for this SDG. Hunger prevalence is estimated to have increased by about 152 million people in 2023 relative to the year 2019 with approximately 713–757 million people (8.9 and 9.4% of the global population, respectively) estimated to be suffering from undernutrition (Food and Agricultural Organization of the United Nations, 2024). The high-quality protein content and superior bioavailability, together with low production costs, suggest that chickpeas could therefore play a vital role in addressing protein-energy malnutrition, particularly among young children and infants in developing countries such as in Asia and Africa (Das and Ghosh, 2012). On the other hand, many developed countries also face malnutrition in the form of overnutrition and there is a pressing need to reduce overall energy intakes whilst ensuring adequate macro and micronutrient intakes. Many societies are also experiencing concurrent challenges of both over and undernutrition within the backdrop of today's climate change crisis (Swinburn et al., 2019).

Chickpeas production and consumption also link well with other SDGs, including SDG 3 (Good Health and Wellbeing) because of their numerous health benefits, as mentioned in earlier sections. Furthermore, chickpeas contribute to SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) through promotion of more sustainable agricultural practices. Legumes have a nitrogen -saving potential which highlights its recommended use in crop-rotation systems, specifically for chickpeas, a study utilizing a chickpea-wheat rotation system, in the Italian region of Apulia, was found to improve environmental impact, with improved soil quality and lower use of fertilizer, and higher profit margins whilst also promoting biodiversity. Controlling the fertilizer used remains critical to ensure the environmental advantage (Lago-Olveira et al., 2023). Chickpeas also contribute to resilient farming in semi-arid regions due to their drought tolerance (Food and Agricultural Organization of the United Nations, 2022). In addition, the low carbon footprint takes an important role in sustainability by reducing environmental impact. It is reported that pulses have lower carbon and water footprints compared to other foods, specifically for US pulses, the greenhouse gas emissions (GHG), calculated as CO_2 equivalents, are reported at 0.27 kg CO_2e/kg using rain as the primary water source, and slightly higher when irrigation systems are utilized, at 0.31 kg CO2e/kg (Gustafson, 2017). Diversifying cropping systems is a crucial aspect for agricultural sustainability since it strengthens the land against diseases, pests, and changing environmental conditions. The implementation of chickpea, among other important crops, in crop rotation systems reduces land exhaustion and pest or pathogen spread, since different crops typically attract different parasites (Li et al., 2019).

The comprehensive incorporation of plant-based products, such as chickpeas, into sustainable food systems can significantly reduce diet-associated greenhouse gas emissions while simultaneously promoting ecological resilience (Godfray et al., 2010). The systematic integration of chickpeas into global dietary patterns therefore supports the transformative shift towards healthier and environmentally sustainable food systems which typically characterize healthy Mediterranean dietary patterns (Carlini et al., 2024). Chickpea research topics have developed through the years, moving from traditional practices, to economic research and now with a recent move towards sustainability and environmental impact reduction considerations (Calia et al., 2024).

As the global population continues to grow, the negative impact of climate change on agricultural yields and overall food provision becomes an even larger threat. Climate change has been shown to cause significant losses in plant production efficiency and lowers the nutritional quality of products (Shahzad et al., 2021) mainly due to abiotic stress factors. This scenario necessitates the implementation of breeding programs targeting improved hardiness to abiotic stresses, like drought, heat, salinity and cold, as well as the development of disease-resistant varieties. Chickpea is a popular crop grown mainly in arid and semi-arid environments on soils of poor agricultural quality where socio-economic struggles are most pressing. It is noteworthy to point out that climatic limitations in northern parts of the world usually restrict chickpea cultivation (Fikre et al., 2020; Food and Agricultural Organization of the United Nations, 2022). Water insecurity is one negative consequence of climate change, characterized by increasing drought conditions, and lower rainfall, causing increased water demand and decreased chickpeas (and other legumes) production. High soil temperatures hamper not only with photosynthesis and respiration but also with the essential nitrogen fixation process that allows chickpeas to grow on poor soils (Naveed et al., 2025) The chickpea crop therefore exhibits variable yields in production and quality when grown in climate change hotspot regions, mainly due to water evaporation from the soils (López-Bellido et al., 2007). This becomes particularly critical in areas where populations are at greatest risk of malnutrition. Trade-offs are present between yields, water usage and carbon emissions (Kyoi et al., 2024). Water use efficiency is a necessity, such that crucially employing strategies to improve tilling, irrigation approaches, together with strategies that promote water conservation and water management, are required. Positive results were attained, for example, by utilizing watering only in critical growth phases of the chickpea crop (Sadeque et al., 2025). A latitudinal shift towards wetter territories may also be a solution, providing the ideal conditions for chickpea cultivation. The possible solutions for higher yields and resilience to both abiotic and biotic stresses are therefore directed towards the utilization of modern techniques, the development of chickpea varieties which are more resilient to these current environmental challenges and which have enhanced nutritional values, (e.g., increased protein or micronutrient value).

5.2 Consumers' acceptability and barriers towards chickpea consumption

Chickpeas are widely used in different culinary dishes, for example, in Middle Eastern cuisine, they are essential ingredients in hummus and falafel. Indian cuisine also incorporates chickpeas into chana masala, while Mediterranean cuisine has included this crop through the years in many different meals including soups and salads (Wood and Grusak, 2007). When seeds are consumed as a whole, there is normally a higher preference for large, uniform, and light-colored chickpeas, and also chickpeas with a creamier texture, which can be utilized to produce drinks (Sharma and Singh, 2024). In settings where chickpeas do not usually form part of the traditional diet, they are usually promoted as a protein-rich food source. When selecting chickpeas, however, consumers consider not only their nutritional value but also their physical and sensory attributes. While ethical arguments play a key role in promoting plant-based diets, significant improvements in sensory quality and resemblance to meat are also considered critical from a consumer perspective (Elzerman et al., 2011; Hoek et al., 2011). In this sense, catering and food production organizations have an important role to play. While younger, urban populations usually exhibit greater acceptance towards trying out novel foods and shifting towards plant-based diets, targeted communication strategies are essential to increased adoption. Older generations, in turn, tend to have a high preference towards consuming legumes, as part of a traditional diet. Considerations on how to encourage catering and food production personnel to include legumes within their dishes will permit further integration of chickpeas into sustainability programs and increase accessibility to all (Magrini et al., 2021; Palnau et al., 2022).

The gluten-free nature of chickpeas has increased the popularity of chickpea flour in breads, for example, making it a promising alternative for gluten-intolerant consumers (Vinod et al., 2023). Consumers also look for plant-based milk alternatives, due to lactose intolerance concerns, or when selecting vegetarian and vegan options. Plant-based milks, such as those derived from almond, rice and oats, contain very small amounts of protein, calcium and iron compared to cow's milk (Mäkinen et al., 2016; Singhal et al., 2017). Although industrial plant-based milk analogs are often fortified with calcium and vitamin D, the bioavailability of these nutrients has not been adequately investigated. Furthermore, many manufacturers use low-cost additives to improve sensory and technological properties, resulting in products with lower nutritional quality. Initial studies show reasonable consumer acceptability for fresh chickpea drinks compared to fermented ones (Wang et al., 2018).

However, despite their numerous benefits, challenges exist that may impede the widespread adoption of chickpea products into population diets. Overcoming these barriers is essential to maximize the potential and integration of chickpeas into sustainable food systems. Traditions change through the years, bringing about concomitant changes in consumer dietary habits as food systems become increasingly globalized. Time restrictions and urbanization, provoke the need for utilizing faster methods of cooking or ordering take-aways, all key contributory causes of the modern 'nutrition transition'. This can then lead to increased intakes of fast, ultraprocessed types of foods, known to be associated with negative health outcomes. Factors such as cultural preferences for meat, affordability concerns, and a lack of culinary knowledge about legumes have also been reported as challenges to consumption (de Boer et al., 2013). Nevertheless, the development of innovative and healthy legume-based products and targeted educational campaigns can foster acceptance and facilitate a move to healthier dietary transitions (Amoah et al., 2023; Austgulen et al., 2018). Providing information on how legumes, including chickpea consumption, are aligned to dietary guidelines can also help increase their intakes.

Ensuring consumer acceptance after preparing chickpeas is also critical for consumption taking also into account the population in context. An example is a study looking at the effects of household-level processing (soaking, germination, and cooking) on chickpeas grown in Ethiopia which concluded that there were no changes in sensorial acceptance, no reductions in micronutrient concentrations (iron, zinc, and calcium) but with marked reductions in antinutrient content (Haileslassie et al., 2019). Legumes can therefore be an attractive option for the food industry which can also be involved in overcoming these consumption barriers by developing more product varieties and promote the use of sustainable processing methods, including less wastage (Augustin et al., 2024).

5.3 Farmers' perspectives, and chickpea supply chains case studies

Economic considerations are crucial for chickpea farmers because they have to consider input costs when anticipating profits. Small-scale farmers face barriers associated with infrastructure, costs and low-yielding varieties which add to increased poverty risk in these households. Affordability is a key concern in the implementation of new strategies particularly for small-scale farmers who are the most vulnerable to suffering economic limitations (Kyoi et al., 2024). A modelling study, in a chickpea-producing region, concluded that improved chickpea varieties, through the adoption of advanced technological processes, can contribute to increased market participation, increasing profitability and attainment of the global SDGs (Tabe-Ojong et al., 2022). The chickpea market is generally considered a niche market, with a relatively small supply chain, but factors beyond simply color, pod size and freshness are considered as crucial trading points. Socio-demographic factors such as gender (women would find it harder to process and sell the chickpeas away from their farms because of increased labor requirements), family size, as well as costs and closeness to market also come into play in Ethiopia, for example. However, value additions such as preparing the seeds (soaking, cooking), packaging and the provision of labels for the product, are also considered important to improve the presence of chickpea across more selling points, such as supermarkets (Zewde and Fikre, 2019).

In Central Europe, wetter climates caused chickpeas to underperform, both in grain and protein yield, in comparison to pea and barley (Neugschwandtner et al., 2015). In southern regions, like Italy, crop rotation "wheat-chickpea" contributed to soil fertilization and also higher incomes for farmers as chickpeas had a higher market price (Lago-Olveira et al., 2023). Research therefore demonstrates that farmers who follow improved agronomic practices, specifically utilizing high-yielding, disease-resistant varieties, would increase profitability. For example, in India, frontline demonstrations and integrated crop management practices showed positive results including yield increases relative to conventional methods, as well as higher net returns and benefit–cost ratios (Meena et al., 2024; Sharma and Singh, 2024). Empirical case studies across South Asia, the Middle East and Africa demonstrate how integrated value-chain strategies, from seed system innovations and participatory breeding, to processing infrastructure and market development, can substantially enhance chickpea productivity, farmer incomes, and consumer accessibility to this crop. Another example is in India's Bundelkhand region, where a value-chain analysis (2019–2021) reported that processing chickpeas into products such as split pulses (dal), flour (besan), and packaged wholegrain, yielded value additions of approximately $230 to $390 per metric ton, with processors capturing the largest share of value and farmers retaining between 58.7 and 69.7% of the retail consumer price (Sah et al., 2022). Similarly, in Ethiopia, the Tropical Legumes III program facilitated the establishment of farmer-led seed societies and innovation platforms, which significantly improved chickpea yields, increasing from 0.78 to 1.19 t/ha, and expanding the area with improved cultivars by 68% (Sah et al., 2021). In another Ethiopian study, producers retained up to 83.3% of the seed value, with net market margins of 53.7%, highlighting the role of community-based seed systems in improving profitability (Adimasu et al., 2024). In Lebanon, the FAO is collaborating with the Ministry of Agriculture to improve chickpea production by improving seed quality, agricultural practices, and storage facilities, with the goal of meeting 40% of national demand domestically by the year 2030, with 85% of the output projected to meet premium quality standards and with a projected 25% increase in sector employment (Food and Agriculture Organization of the United Nations and Ministry of Agriculture, Lebanon, 2025). These diverse regional case studies highlight the critical importance of coordinated, multi-stakeholder approaches across the chickpea value chain in achieving both agronomic improvements and socio-economic benefits.

6 Chickpeas, their inclusion in food policies and regulatory considerations

Although recognized for their environmental and nutritional benefits, chickpeas have historically been underrepresented in agricultural policies compared to major staple crops and are often grouped under the broader category of legumes, without specific focus in policies. Government policies and trade agreements play a significant role in influencing farmers' decisions for chickpea production. The Common Agricultural Policy (CAP) includes some support for pulses, particularly through coupled income support and eco-schemes, with several European Union Member States incentivizing their cultivation (European Commission, 2023). Historically, the CAP focused on cereals and livestock, leaving legumes underfunded (European Commission, 2023). Chickpeas therefore remain a marginal crop in Europe, with low production levels and a heavy reliance on imports. The EU 'Green Deal' and 'Farm to Fork Strategy' promote sustainable food systems, favoring nitrogen-fixing crops like chickpeas. Additionally, the 'Farm to Fork' encourages a shift towards plant-based diets, where chickpeas can serve as a sustainable protein source (European Commission, 2020). At the global level, FAO recognizes chickpeas as a key crop for food security and climate resilience. Pulses were also promoted during the International Year of Pulses and remain central in FAO's sustainability strategies (Food and Agricultural Organization of the United Nations, 2016).

Bechthold et al. (2018) highlight that despite evidence of a shift, there is still relative lack of sustainability considerations included within many countries' dietary guidelines. In Spain, the lack of emphasis on increased fish and legumes intakes and reduced red meat consumption were described in a recent study looking at school and social care settings and their procurement strategies (Gaitán-Cremaschi and Valbuena, 2024). Adaptability through changes in menus, including developing seasonal plans, for example, and tackling challenges such as budget/affordability concerns were considered crucial in ensuring the implementation of successful sustainable procurement strategies. Policy changes could lead to favorable outcomes, one such example was within a municipality in Brazil implementing changes in purchasing criteria over a two-year period, which included direct purchase from local farms, noted increased inclusion of legume and other healthy products in school meals (Soares et al., 2017). Pledges to increase the amounts of plant-based foods offered in school meals have also been implemented. Good practice examples include the Swedish city of Umeå, where a minimum of one vegetarian option is offered on a daily basis (International Council for Local Environment Initiatives, ICLEI European Secretariat, 2023).

Meanwhile, policies that promote chickpea cultivation and consumption worldwide, along with other legumes, should consider also that the majority of the produced crop originates from Asia and Australia, where consumption is higher. The success of government intervention and policy inclusions can be drawn from countries such as India, where market support, technology advancement (including the development of drought resistant cultivars) and procurement enablement, have had a positive impact by increasing local yields, therefore requiring lower importation and reducing costs (Malik, 2021). Also in India, policies such as the Minimum Support Price for pulses, including chickpeas, help stabilize prices and encourage production. These policies also aim to incorporate the ecological benefits of pulses, such as nitrogen fixation, into incentive structures (Reddy et al., 2024). Initiatives to expand domestic production of chickpeas, such as those in Southern Sweden, focus on developing local markets and reducing reliance on imports. Adoption of chickpea varieties with improved nutritional and agronomic traits will maximize farmers' profits, expanding processing and selling opportunities, especially in international markets (Food and Agriculture Organization of the United Nations, 2019; Knights, 2024).

Overall, this crop therefore still faces challenges of limited policy support, agronomic constraints, and underdeveloped value chains particularly in Europe. Strengthening research, using targeted subsidies, and improving processing infrastructure and including legumes, such as chickpeas, in country-specific procurement policy and dietary guidelines could improve chickpea integration into value chain food systems. Figure 1 is a visual representation summarizing the main concepts of the chickpea value chain.

7 Discussion

The main aims of this literature review were to provide an updated overview for chickpeas, their nutritional benefits, antinutrient content and their mitigation, sustainability and environmental perspectives. These are all crucial considerations which are required to meet today's global demands for an

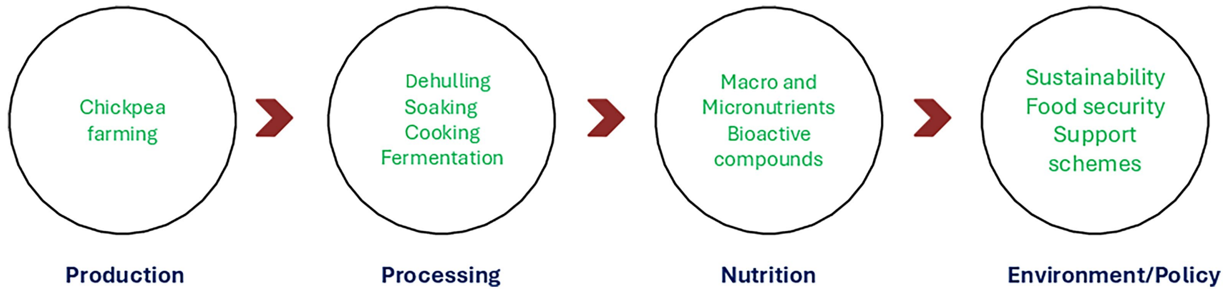

FIGURE 1
The chickpea value chain.

affordable, accessible and efficient food supply. The chickpea crop represents more than just a source of essential nutrients. Varietal differences in genetic factors, agronomic and climatic conditions, which influence nutrient accumulation, as well as processing factors, all contribute to the health benefits derived when consuming chickpeas. These include improved glycemic control, weight management, modulation of inflammation in cardiovascular conditions, cancer prevention, higher mineral absorption, and enhancements in gut and bone health. The key stakeholders are the consumers, farmers, research scientists, who all need to be involved in interdisciplinary dialogue, and work with decision makers to ensure the inclusion of chickpeas in key policies which is critical for enabling chickpea food systems transformations. Stronger inclusive practices, through the rethinking of the traditional 'farm to fork' approach, will benefit all the players involved. Considerations need to go beyond simply food production and yields, and reinforce the inclusion of sociocultural, socio-economic and equity aspects.

Some research gaps exist which warrant further exploration. These include a limited understanding on the nutritional diversity of chickpea cultivars, advanced technology inputs that focuses on nutritional and health outcomes, and further study on the environmental and economic consequences. There is also limited data and understanding regarding the impact of processing on anti-nutritional factors and overall nutrient bioavailability, storage effects, and labeling issues. The following actionable recommendations are therefore suggested:

Long-term clinical studies are needed to improve the evidence base on the use of chickpeas in plant-based foods and maximizing their potential as functional foods with improved population health outcomes. It is crucial also to increase provision to institutions, such as schools and hospitals, and promote their cultural integration within the population in context. Further education for all stakeholders operating within chickpea supply chains is suggested, to impart knowledge and further skills, that will lead to the adoption of more environmentally friendly and efficient agricultural practices. Supporting organic and agroecological chickpea production, with farmers and processors being the key beneficiaries, through the use of grants and other schemes, would help support sustainable production and biodiversity enhancement, Current case study examples could provide the necessary framework for adopting and extending successful practices to other countries or regions. More subsidies are needed to develop interventions that link traditional and sustainable processes and which could provide the necessary nudging to move towards more acceptable climate-smart practices. Public health strategies require both top-down and bottom-up approaches to increase chickpea consumption. The diffusion of health and marketing campaigns could support this drive by promoting the health benefits of chickpeas and improve their integration into consumers' dietary plans. Figure 2 represents the chickpea food systems map with approaches aiming to improve production and consumption with the ultimate objectives of improving population health and reducing environmental impact.

In conclusion, challenges remain in innovations in product development, and advanced processing technologies. Chickpeas need to stand out further as functional and practical components of healthy and sustainable diets, with their beneficial nutritional and environmental profile securing their contribution to global food security and food systems transformations to support a healthier population and planet.

Author contributions

CC: Project administration, Visualization, Writing – original draft, Writing – review & editing. PJ: Writing – original draft, Writing – review & editing. BA: Writing – original draft, Writing – review & editing. JZ: Writing – original draft, Writing – review & editing. EC: Writing – original draft, Writing – review & editing. HK: Writing – original draft, Writing – review & editing. NĆ: Writing – original draft, Writing – review & editing, Conceptualization, Methodology. İK: Writing – original draft, Writing – review & editing. EY: Writing – original draft, Writing – review & editing. GT: Writing – original draft, Writing – review & editing. ASe: Writing – original draft, Writing – review & editing. DÖ: Writing – original draft, Writing – review & editing. AB: Writing – original draft, Writing – review & editing. ÖÖ: Writing – original draft, Writing – review & editing. SG: Writing – original draft, Writing – review & editing. KŠ: Writing – original draft, Writing – review & editing. ASi: Writing – original draft, Writing – review & editing. SR: Writing – original draft, Writing – review & editing. FB: Writing – original draft, Writing – review & editing. TI: Writing – original draft, Writing – review & editing. MC: Writing – original draft, Writing – review & editing. AO: Writing – original draft, Writing – review & editing. BB: Writing – original draft, Writing – review & editing. MD: Writing – original

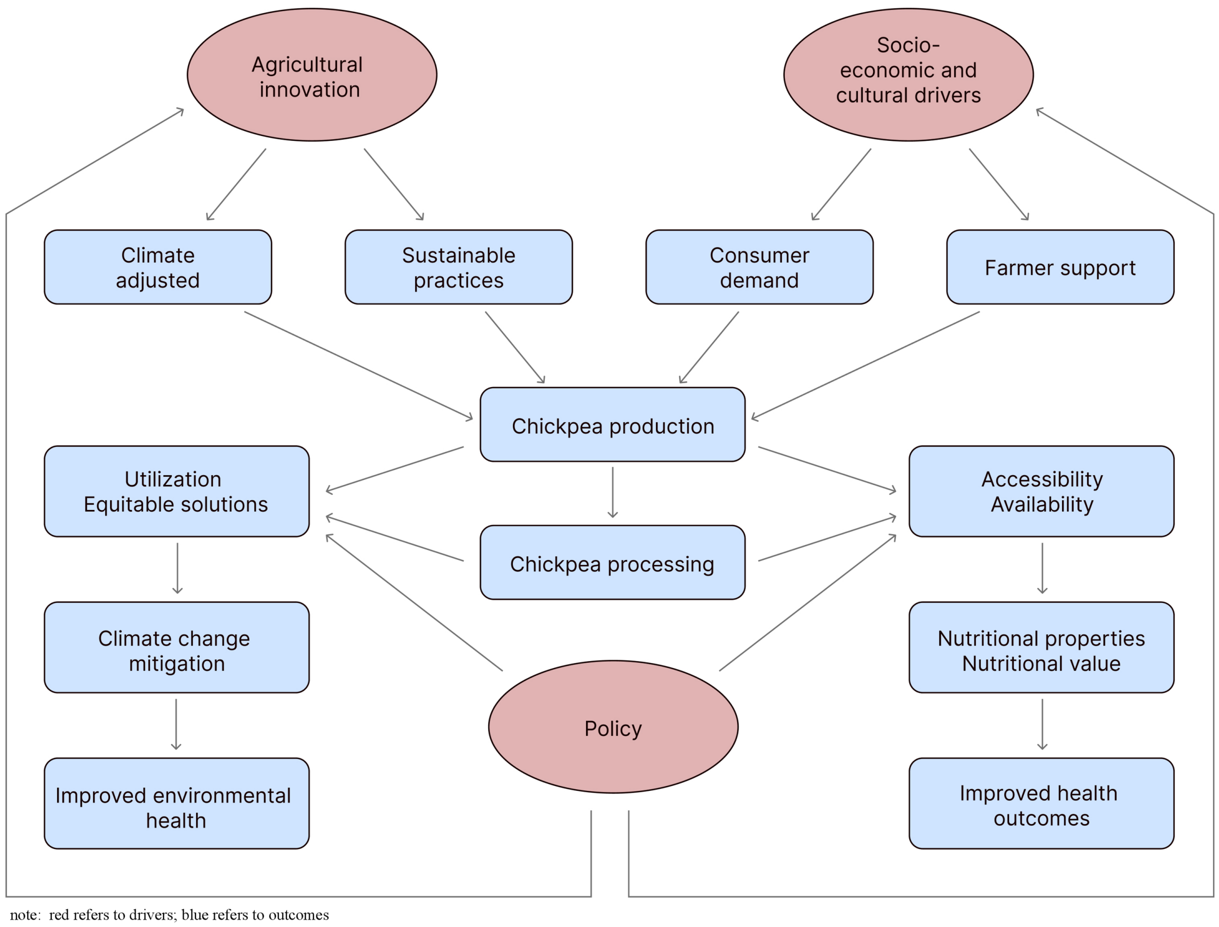

FIGURE 2
Chickpea food systems approach.

draft, Writing – review & editing. SN: Writing – original draft, Writing – review & editing. MK: Writing – original draft, Writing – review and editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This research was funded by COST Action DIVERSICROP, CA22146, supported by COST (European Cooperation in Science and Technology). COST Action CA22146-Harnessing the potential underutilized crops to promote sustainable food production. This research was also supported by the Ministry of Science, Technological Development and Innovation, Republic of Serbia (Grant No. 451-03-136/2025-03/200015 and 451-03-136/2025-03/200003). DIVERSICROP activities in Bulgaria are supported by Bulgarian National Science Fund under "Historical and contemporary aspects of the cultivation and use of neglected crops" project (КП-06-КОСТ/4.21.05.2024).

Conflict of interest

BB was employed by ESSRG Nonprofit Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Gen AI was used in the creation of this manuscript. The authors acknowledge the use of ChatGPT (version 4) for sentence and grammar editing in some sections of the manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

References

Abu Risha, M., Rick, E.-M., Plum, M., and Jappe, U. (2024). Legume allergens pea, chickpea, lentil, lupine and beyond. *Curr Allergy Asthma Rep* 24, 527–548. doi: 10.1007/s11882-024-01165-7

Adimasu, S., Teshale, S., and Fikre, G. (2024). Value chain analysis of community-based chickpea seed: the case of selected districts of Gurage zone, southern Ethiopia. *J. Biodivers. Environ. Sci.* 25, 31–41.

Aguilera, Y., Martín-Cabrejas, M. A., Benítez, V., Mollá, E., López-Andréu, F. J., and Esteban, R. M. (2009). Changes in carbohydrate fraction during dehydration process of common legumes. *J. Food Compos. Anal.* 22, 678–683. doi: 10.1016/j.jfca.2009.02.012

Ahmadi, N., Mokaberinejad, R., Saeidi, A., Zandi, A., Leach, M. J., and Pasalar, M. (2020). The effect of chickpea broth on knee osteoarthritis—a pilot non-randomised open-labeled clinical study. *Adv. Integr. Med.* 7, 121–125. doi: 10.1016/j.aimed.2020.01.004

Aisa, H. A., Gao, Y., Yili, A., Ma, Q., and Cheng, Z. (2019). Beneficial role of chickpea (Cicer arietinum L.) functional factors in the intervention of metabolic syndrome and diabetes mellitus in bioactive food as dietary interventions for diabetes. eds. R. R. Watson and V. R. Preedy. (Amsterdam: Elsevier), 615–627.

Ajay, A., Gaur, S. S., Shams, R., Dash, K. K., Mukarram, S. A., and Kovács, B. (2024). Chickpeas and gut microbiome: functional food implications for health. *Heliyon* 10:e39314. doi: 10.1016/j.heliyon.2024.e39314

Alajaji, S. A., and El-Adawy, T. A. (2006). Nutritional composition of chickpea (Cicer arietinum L.) as affected by microwave cooking and other traditional cooking methods. *J. Food Comp. Anal.* 19, 806–812. doi: 10.1016/j.jfca.2006.03.015

Alcalá-Santiago, Á., Toscano-Sánchez, R., Márquez-López, J. C., González-Jurado, J. A., Fernández Pachón, M. S., García-Villanova, B., et al. (2024). The synergic immunomodulatory effect of vitamin D and chickpea protein hydrolysate in THP-1 cells: an invitro approach. *Int. J. Mol. Sci.* 25:12628. doi: 10.3390/ijms252312628

Alsalman, F. B., and Ramaswamy, H. S. (2020). Reduction in soaking time and anti-nutritional factors by high pressure processing of chickpeas. *J. Food Sci. Technol.* 57, 681–690. doi: 10.1007/s13197-020-04294-9

Amoah, I., Ascione, A., Muthanna, F. M. S., Feraco, A., Camajani, E., Gorini, S., et al. (2023). Sustainable strategies for increasing legume consumption: culinary and educational approaches. *Foods* 12:2265. doi: 10.3390/foods12112265

Ashokkumar, K., Diapari, M., Jha, A. B., Tar'an, B., Arganosa, G., and Warkentin, T. D. (2015). Genetic diversity of nutritionally important carotenoids in 94 pea and 121 chickpea accessions. *J. Food Compos. Anal.* 43, 49–60. doi: 10.1016/j.jfca.2015.04.014

Austgulen, M. H., Skuland, S. E., Schjøll, A., and Alfnes, F. (2018). Consumer readiness to reduce meat consumption for the purpose of environmental sustainability: insights from Norway. *Sustainability* 10:3058. doi: 10.3390/su10093058

Augustin, M. A., Chen, J. Y., and Ye, J. H. (2024). Processing to improve the sustainability of chickpea as a functional food ingredient. *J. Sci. Food Agric.* 104, 8397–8413. doi: 10.1002/jsfa.13532

Bar-El Dadon, S., Abbo, S., and Reifen, R. (2017). Leveraging traditional crops for better nutrition and health - the case of chickpea. *Trends Food Sci. Technol.* 64, 39–47. doi: 10.1016/j.tifs.2017.04.002

Bechthold, A., Boeing, H., Tetens, I., Schwingshackl, L., and Nöthlings, U. (2018). Perspective: food-based dietary guidelines in Europe—scientific concepts, current status, and perspectives. *Adv. Nutr.* 9, 544–560. doi: 10.1093/advances/nmy033

Behl, T., Rana, T., Alotaibi, G. H., Shamsuzzaman, M., Naqvi, M., Sehgal, A., et al. (2022). Polyphenols inhibiting MAPK signalling pathway mediated oxidative stress and inflammation in depression. *Biomed. Pharmacother.* 146:112545. doi: 10.1016/j.biopha.2021.112545

Bektaş, M., and Ertop, M. H. (2021). Phytic acid content and in-vitro digestibility of several cereal and legume types treated with different processes. *Ukr. Food J.* 10, 507–523. doi: 10.24263/2304974X-2021-10-3-7

Brown, E. M. (2013). Role of the calcium-sensing receptor in extracellular calcium homeostasis. *Best Pract. Res. Clin. Endocrinol. Metab.* 27, 333–343. doi: 10.1016/j.beem.2013.02.006

Calia, C., Pulvento, C., Sellami, M. H., Tedone, L., Ruta, C., and De Mastro, G. (2024). A bibliometric analysis of chickpea agronomic practices in the world during 45 years of scientific research. *Legume Sci.* 6:e219. doi: 10.1002/leg3.219

Carlini, B., Lucini, C., and Velázquez, J. (2024). The role of legumes in the sustainable Mediterranean diet: analysis of the consumption of legumes in the Mediterranean population over the last ten years a PRISMA statement methodology. *Sustainability* 16:3081. doi: 10.3390/su16073081

Carretta, M. D., Quiroga, J., López, R., Hidalgo, M. A., and Burgos, R. A. (2021). Participation of short-chain fatty acids and their receptors in gut inflammation and colon cancer. *Front. Physiol.* 12:662739. doi: 10.3389/fphys.2021.662739

Chang, Y., Alli, I., Molina, A. T., Konishi, Y., and Boye, J. I. (2012). Isolation and characterization of chickpea (*Cicer arietinum* L.) seed protein fractions. *Food Bioprocess Technol.* 5, 618–625. doi: 10.1007/s11947-009-0303-y

Chávez-Ontiveros, J., Reyes-Moreno, C., Ramírez-Torres, G. I., Figueroa-Salcido, O. G., Arámburo-Gálvez, J. G., Montoya-Rodríguez, A., et al. (2022). Extrusion improves the antihypertensive potential of a 'kabuli' chickpea (*Cicer arietinum* L.) protein hydrolysate. *Foods* 11:2562. doi: 10.3390/foods11172562

Ciudad-Mulero, M., Vega, E. N., García-Herrera, P., Pedrosa, M. M., Arribas, C., Berrios, J. D. J., et al. (2022). Extrusion cooking effect on carbohydrate fraction in novel gluten-free flours based on chickpea and rice. *Molecules* 27:1143. doi: 10.3390/molecules27031143

Ciqual-Anses. (2020). French Food Composition Table. Available online at: https://ciqual.anses.fr (Accessed September 22, 2025).

Crujeiras, A. B., Parra, D., Abete, I., and Martínez, J. A. (2007). A hypocaloric diet enriched in legumes specifically mitigates lipid peroxidation in obese subjects. *Free Radic. Res.* 41, 498–506. doi: 10.1080/10715760601131935

Das, A., and Ghosh, P. K. (2012). Role of legumes in sustainable agriculture and food security: an Indian perspective. *Outlook Agric.* 41, 279–284. doi: 10.5367/oa.2012.0109

de Boer, J., Schösler, H., and Boersema, J. J. (2013). Motivational differences in food orientation and the choice of snacks made from lentils, locusts, seaweed or "hybrid" meat. *Food Qual. Prefer.* 28, 32–35. doi: 10.1016/j.foodqual.2012.07.008

de Camargo, A. C., Favero, B. T., Morzelle, M. C., Franchin, M., Alvarez-Parrilla, E., de la Rosa, L. A., et al. (2019). Is chickpea a potential substitute for soybean? Phenolic bioactives and potential health benefits. *Int. J. Mol. Sci.* 20:2644. doi: 10.3390/ijms20112644

Dhillon, P. K., Bowen, L., Kinra, S., Bharathi, A. V., Agrawal, S., Prabhakaran, D., et al. (2016). Legume consumption and its association with fasting glucose, insulin resistance and type 2 diabetes in the Indian migration study. *Public Health Nutr.* 19, 3017–3026. doi: 10.1017/S1368980016001233

Dida Bulbula, D., and Urga, K. (2018). Study on the effect of traditional processing methods on nutritional composition and antinutritional factors in chickpea (*Cicer arietinum*). *Cogent Food Agric.* 4:1422370. doi: 10.1080/23311932.2017.1422370

El-Adawy, T. A. (2002). Nutritional composition and antinutritional factors of chickpeas undergoing different cooking methods and germination. *Plant Foods Hum. Nutr.* 57, 83–97. doi: 10.1023/A:1013189620528

Elango, D., Rajendran, K., Van der Laan, L., Sebastiar, S., Raigne, J., Thaiparambil, N. A., et al. (2022). Raffinose family oligosaccharides: friend or foe for human and plant health? *Front. Plant Sci.* 13:829118. doi: 10.3389/fpls.2022.829118

Elzerman, J. E., Hoek, A. C., van Boekel, M. A., and Luning, P. A. (2011). Consumer acceptance and appropriateness of meat substitutes in a meal context. *Food Qual. Prefer.* 22, 233–240. doi: 10.1016/j.foodqual.2010.10.006

European Commission. (2020). Farm to fork strategy: for a fair, healthy and environmentally-friendly food system. Available online at: https://ec.europa.eu (Accessed May 25, 2025).

European Commission. (2023). The new common agricultural policy: 2023-2027. Available online at: https://agriculture.ec.europa.eu (Accessed May 15, 2025).

European Food Safety Authority (2019). Dietary reference values for nutrients. Summary Report. Available online at: https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/sp.efsa.2017.e15121 (Accessed September 20, 2025).

European Food Safety Authority (2021). Food composition data. Available online at: https://www.efsa.europa.eu/en/data-report/food-composition-data (Accessed September 20, 2025).

Faridy, J. M., Stephanie, C. M., Gabriela, M. O., and Cristian, J. (2020). Biological activities of chickpea in human health (*Cicer arietinum* L.). A review. *Plant Foods Hum. Nutr.* 75, 142–153. doi: 10.1007/s11130-020-00814-2

Fikre, A., Desmae, H., and Ahmed, S. (2020). Tapping the economic potential of chickpea in sub -Saharan Africa. *Agronomy* 10:1707. doi: 10.3390/agronomy10111707

Food and Agricultural Organization of the United Nations. (2016). International year of pulses 2016: Nutritious seeds for a sustainable future. Available online at: https://www.fao.org (Accessed May 20, 2025).

Food and Agriculture Organization of the United Nations. (2019). The global economy of pulses. Rome. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/2c70eed3-4170-4b0e-963b-995323fe94a1/content (Accessed September 5, 2025).

Food and Agricultural Organization of the United Nations. (2022). The role of pulses in sustainable food systems. Available online at: https://www.fao.org (Accessed May 25, 2025).

Food and Agricultural Organization of the United Nations. (2023). Statistical year book. World food and agriculture. 2023. Available online at: https://www.fao.org (Accessed May 25, 2025).

Food and Agricultural Organization of the United Nations (2024). The state of food security and nutrition in the world 2024. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/dc4a2fdf 7f8b-4093-899e-ed5ea24e4889/content (Accessed June 25, 2025).

Food and Agricultural Organization of the United Nations. (2025). FAOSTAT database 2025. Crops and livestock products. Available online at: https://www.fao.org/faostat/en/#data (Accessed May 25, 2025).

Food and Agriculture Organization of the United Nations and Ministry of Agriculture, Lebanon. (2025). The chickpea value chain in Lebanon: A great opportunity for development. Available online at: https://www.fao.org/lebanon/home/the-chickpea-value-chain-in-lebanon--a-great-opportunity-for-development/en (Accessed September 5, 2025).

Fuso, A., Donna, M., Varetto, P., Pigna, G., Bonzanini, F., Caligiani, A., et al. (2025). Effect of soaking and roasting on antinutritional factors content in different genotypes of soybean and chickpea. *J. Food Compos. Anal.* 147:108003. doi: 10.1016/j.jfca.2025.108003

Gaitán-Cremaschi, D., and Valbuena, D. (2024). Examining purchasing strategies in public food procurement: integrating sustainability, nutrition, and health in Spanish school meals and social care Centre. *Food Policy* 129:102742. doi: 10.1016/j.foodpol.2024.102742

Gangola, M. P., Båga, M., Gaur, P. M., and Chibbar, R. N. (2014). Chickpea – nutritional quality and role in alleviation of global malnourishment. *Legume Perspect.* 3, 33–35.

Gaur, P. M., Singh, M. K., Samineni, S., Sajja, S. B., Jukanti, A. K., Kamatam, S., et al. (2016). Inheritance of protein content and its relationships with seed size, grain yield and other traits in chickpea. *Euphytica* 209, 253–260. doi: 10.1007/s10681-016-1678-2

Godfray, H. C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., et al. (2010). Food security: the challenge of feeding 9 billion people. *Science* 327, 812–818. doi: 10.1126/science.1185383

Gu, S. Y., Shin, H. C., Kim, D. J., Park, S. U., and Kim, Y. K. (2021). The content and health risk assessment of micro and toxic elements in cereals (oat and quinoa), legumes (lentil and chick pea), and seeds (chia, hemp, and flax). *J. Food Compos. Anal.* 99:103881. doi: 10.1016/j.jfca.2021.103881

Gundogan, R., Tomar, G. S., Karaca, A. C., Capanoglu, E., and Tulbek, M. C. (2024). "Chickpea protein: sustainable production, functionality, modification, and applications" in sustainable protein sources. eds. S. Nadathur, J. P. D. Wanasundara and L. Scanlin (Amsterdam: Elsevier), 185–199.

Gupta, R. K., Gupta, K., Sharma, A., Das, M., Ansari, I. A., and Dwivedi, P. D. (2017). Health risks and benefits of chickpea (*Cicer arietinum*) consumption. *J. Agric. Food Chem.* 65, 6–22. doi: 10.1021/acs.jafc.6b02629

Gupta, N., Bisen, P. S., and Bhagyawant, S. S. (2018). Chickpea lectin inhibits human breast cancer cell proliferation and induces apoptosis through cell cycle arrest. *Protein Pept. Lett.* 25, 353–362. doi: 10.2174/0929866525666180406142900

Gustafson, D. I. (2017). Greenhouse gas emissions and irrigation water use in the production of pulse crops in the United States. *Cogent Food & Agric.* 3:1334750. doi: 10.1080/23311932.2017.1334750

Haileslassie, H. A., Henry, C. J., and Tyler, R. T. (2019). Impact of pre-treatment (soaking or germination) on nutrient and anti-nutrient contents, cooking time and acceptability of cooked red dry bean (*Phaseolus vulgaris* L.) and chickpea (*Cicer arietinum* L.) grown in Ethiopia. *Int. J. Food Sci. Technol.* 54, 2540–2552. doi: 10.1111/ijfs.14165

Heiras-Palazuelos, M., Ochoa-Lugo, M., Gutiérrez-Dorado, R., López-Valenzuela, J. A., Mora Rochín, S., Milán-Carrillo, J., et al. (2013). Technological properties, antioxidant activity and total phenolic and flavonoid content of pigmented chickpea (*Cicer arietinum* L.) cultivars. *Int. J. Food Sci. Nutr.* 64, 69–76. doi: 10.3109/09637486.2012.694854

Hoek, A. C., Luning, P. A., Weijzen, P., Engels, W., Kok, F. J., and De Graaf, C. (2011). Replacement of meat by meat substitutes. A survey on person-and product-related factors in consumer acceptance. *Appetite* 56, 662–673. doi: 10.1016/j.appet.2011.02.001

ICLEI European Secretariat (2023). Report on innovative criteria and models for procurement of sustainable and health school meals. Available online at: https://schoolfood4change.eu/wp-content/uploads/2023/06/D5.1-Innovative-CriteriaModels-for-Proc-of-SustHealthy-School-Meals.pdf (Accessed September 19, 2025).

Jha, A. B., Ashokkumar, K., Diapari, M., Ambrose, S. J., Zhang, H., Tar'an, B., et al. (2015). Genetic diversity of folate profiles in seeds of common bean, lentil, chickpea and pea. *J. Food Compos. Anal.* 42, 134–140. doi: 10.1016/j.jfca.2015.03.006

Kim, Y. S., Young, M. R., Bobe, G., Colburn, N. H., and Milner, J. A. (2009). Bioactive food components, inflammatory targets, and cancer prevention. *Cancer Prev. Res.* 2, 200–208. doi: 10.1158/1940-6207.CAPR-08-0141

Knights, S. (2024). Raising the pulse' road map provides clear signposts to 2030. Available online at: https://groundcover.grdc.com.au/crops/pulses/raising-the-pulse-road-map-provides-clear-signposts-to2030 (Accessed September 5, 2025).

Kyoi, S., Mori, K., and Matsushita, K. (2024). Solution of trade-offs between food production, water use, and climate change mitigation in global agriculture. *Sustain. Dev.* 32, 314–2324. doi: 10.1002/sd.2792

Lago-Olveira, S., Rebolledo-Leiva, R., Garofalo, P., Moreira, M. T., and González-García, S. (2023). Environmental and economic benefits of wheat and chickpea crop rotation in the Mediterranean region of Apulia (Italy). *Sci. Total Environ.* 896:165124. doi: 10.1016/j.scitotenv.2023.165124

Lev-Yadun, S., Gopher, A., and Abbo, S. (2000). The cradle of agriculture. *Science* 288, 1602–1603. doi: 10.1126/science.288.5471.1602

Li, J., Huang, L., Zhang, J., Coulter, J. A., Li, L., and Gan, Y. (2019). Diversifying crop rotation improves system robustness. *Agron. Sustain. Dev.* 39, 1–13. doi: 10.1007/s13593-019-0584-0

López-Bellido, R. J., López-Bellido, L., Benítez-Vega, J., and López-Bellido, F. J. (2007). Tillage system, preceding crop, and nitrogen fertilizer in wheat crop: II. Water utilization. *Agron. J.* 99, 66–72. doi: 10.2134/agronj2006.0026

Luna-Vital, D. A., and de Mejía, E. (2018). Peptides from legumes with anti-gastrointestinal cancer potential: current evidence for their molecular mechanisms. *Curr. Opin. Food Sci.* 19, 30–39. doi: 10.1016/j.cofs.2018.02.012

Magrini, M., Fernandez-Inigo, H., Doré, A., and Pauly, O. (2021). How institutional food services can contribute to sustainable agrifood systems? Investigating legume-serving, legume-cooking and legume-sourcing through France in 2019. *Rev. Agric. Food Environ. Stud.* 102, 297–318. doi: 10.1007/s41130-021-00146-y

Mahbub, R., Francis, N., Blanchard, C., and Santhakumar, A. (2021). The anti-inflammatory and antioxidant properties of chickpea hull phenolic extracts. *Food Biosci.* 40:100850. doi: 10.1016/j.fbio.2020.100850

Mäkinen, O. E., Wanhalinna, V., Zannini, E., and Arendt, E. K. (2016). Foods for special dietary needs: non-dairy plant-based milk substitutes and fermented dairy-type products. *Crit. Rev. Food Sci. Nutr.* 56, 339–349. doi: 10.1080/10408398.2012.761950

Malik, D. P. (2021). Global chickpea production and instability with special reference to India for trade and policy options. *African-Asian J. Rural Dev.* 54, 7–52.

Man, S., Gao, W., Zhang, Y., Huang, L., and Liu, C. (2010). Chemical study and medical application of saponins as anti-cancer agents. *Fitoterapia* 81, 703–714. doi: 10.1016/j.fitote.2010.06.004

Mastrorilli, C., Giudice, M. M. D., Caffarelli, C., et al. (2024). IgE-mediated legume allergy: a pediatric perspective. *J. Pers. Med.* 14:898. doi: 10.3390/jpm14090898

Mathew, S. E., and Shakappa, D. (2024). Comparative nutritional analysis of improved and local chickpea (*Cicer arietinum*) cultivars. *Plant Foods Hum. Nutr.* 79, 539–544. doi: 10.1007/s11130-024-01181-y

Meena, S. N., Meena, L. K., Yadav, S., Jadon, C. K., Dhakad, U., Lal, M., et al. (2024). Chickpea (*Cicer arietinum*)-based intercropping systems in Rajasthan's Hadoti region: productivity and economic viability. *Ind. J. Agron.* 69, 54–60. doi: 10.59797/ija.v69i1.5482

Milán-Noris, A. K., Gutiérrez-Uribe, J. A., Santacruz, A., Serna-Saldívar, S. O., and Martínez Villaluenga, C. (2018). Peptides and isoflavones in gastrointestinal digests contribute to the anti inflammatory potential of cooked or germinated "desi" and "kabuli" chickpea (*Cicer arietinum* L.). *Food Chem.* 268, 66–76. doi: 10.1016/j.foodchem.2018.06.068

Milán-Noris, A. K., Gutierrez-Uribe, J., and Serna-Saldivar, S. (2023). Influence of soaking and boiling on flavonoids and saponins of nine "desi" chickpea cultivars with potential antiproliferative effects. *J. Food Meas. Charact.* 17, 3473–3481. doi: 10.1007/s11694-023-01861-4

Naveed, M., Aslam, M., Ahmed, S. R., Tan, D. K. Y., De Mastro, F., Tariq, M. S., et al. (2025). An overview of heat stress in Chickpea (*Cicer arietinum* L.): effects, mechanisms and diverse molecular breeding approaches for enhancing resilience and productivity. Mol. Breed. 45:2,:18. doi: 10.1007/s11032-025-01538-4

Neugschwandtner, R. W., Wagentristl, H., and Kaul, H. (2015). Nitrogen yield and nitrogen use of chickpea compared to pea, barley and oat in Central Europe. *Int. J. Plant Prod.* 9, 291–304.

Nicolás-García, M., Jiménez-Martínez, C., Perucini-Avendaño, M., Camacho-Díaz, B. H., Jiménez Aparicio, A. R., and Dávila-Ortiz, G. (2021) in Phenolic compounds in legumes: composition, processing and gut health in legume research. eds. J. C. Jimenez-Lopez and A. Clemente. (London UK: IntechOpen).

Oghbaei, M., and Prakash, J. (2020). Effect of dehulling and cooking on nutritional quality of chickpea (*Cicer arietinum* L.) germinated in mineral fortified soak water. *J. Food Compos. Anal.* 94:103619. doi: 10.1016/j.jfca.2020.103619

Padhi, E. M., Liu, R., Hernandez, M., Tsao, R., and Ramdath, D. D. (2017). Total polyphenol content, carotenoid, tocopherol and fatty acid composition of commonly consumed Canadian pulses and their contribution to antioxidant activity. *J. Funct. Foods* 38, 602–611. doi: 10.1016/j.jff.2016.11.006

Palnau, J., Ziegler, M., and Lämmle, L. (2022). You are what you eat and so is our planet: identifying dietary groups based on personality and environmentalism. *Int. J. Environ. Res. Public Health* 19:9354. doi: 10.3390/ijerph19159354

Ramirez, M. L., Cendoya, E., Nichea, M. J., Zachetti, V. G. L., and Chulze, S. N. (2018). Impact of toxigenic fungi and mycotoxins in chickpea: a review. *Curr. Opin. Food Sci.* 23, 32–37. doi: 10.1016/j.cofs.2018.05.003

Real Hernandez, L. M., and Gonzalez de Mejia, E. (2019). Enzymatic production, bioactivity, and bitterness of chickpea (*Cicer arietinum*) peptides. *Compr. Rev. Food Sci. Food Saf.* 18, 1913–1946. doi: 10.1111/1541-4337.12504

Reddy, A. A., Bhagwat, K. D., Tiwari, V. L., Kumar, N., and Dixit, G. (2024). Policies and incentives for promotion of pulses production and consumption: a review. *J. Food Legumes*. doi: 10.59797/jfl.v36.i4.157

Reyes-Moreno, C., Cuevas-Rodríguez, E. O., Milán-Carrillo, J., Cárdenas-Valenzuela, O. G., and Barrón-Hoyos, J. (2004). Solid state fermentation process for producing chickpea (*Cicer arietinum* L)tempeh flour. Physicochemical and nutritional characteristics of the product. *J. Sci. Food Agric.* 84, 271–278. doi: 10.1002/jsfa.1637

Roy, F., Boye, J. I., and Simpson, B. K. (2010). Bioactive proteins and peptides in pulse crops: pea, chickpea and lentil. *Food Res. Int.* 43, 432–442. doi: 10.1016/j.foodres.2009.09.002

Sadeque, A., Ahmed, S., Islam, M. A., Muktadir, M. A., Rahman, M. Z., Islam, M. S., et al. (2025). Enhancing water use efficiency in grain legumes: from agronomic practices to breeding strategies. *J. Plant Nutr.* 1-43, 1–43. doi: 10.1080/01904167.2025.2544701

Sah, U., Chaturvedi, S. K., Dixit, G. P., Singh, N. P., and Gaur, P. (2021). "Organized farmers towards chickpea seed self-sufficiency in Bundelkhand region of India" in Enhancing smallholder farmers' access to seed of improved legume varieties through multi-stakeholder platforms (Springer Singapore), 113–123. doi: 10.1007/978-981-15-8014-7_8

Sah, U., Singh, V., Ojha, J., Katiyar, M., Dubey, S. K., Singh, S. K., et al. (2022). Chickpea value chain in Bundelkhand region of India: an empirical insight. *Indian J. Ext. Educ.* 58, 28–33. doi: 10.48165/IJEE.2022.58406

Sajja, S. B., Samineni, S., and Gaur, P. M. (2017). "Botany of chickpea, the chickpea genome" in The compendium of plant genomes book series. eds. R. Varshney, M. Thudi, and F. Muehlbauer (Cham: Elsevier), 13–24.

Salvi, P. S., and Cowles, R. A. (2021). Butyrate and the intestinal epithelium: modulation of proliferation and inflammation in homeostasis and disease. *Cells* 10:1775. doi: 10.3390/cells10071775

Samtiya, M., Aluko, R. E., and Dhewa, T. (2020). Plant food anti-nutritional factors and their reduction strategies: an overview. *Food Prod. Process. Nutr.* 2, 1–14. doi: 10.1186/s43014-020-0020-5

Sarkar, S., and Bhatia, G. (2021). Writing and appraising narrative reviews. *J. Clin. Sci. Res.* 10, 169–172. doi: 10.4103/jcsr.jcsr_1_21

Schwingshackl, L., Schwedhelm, C., Hoffmann, G., Knüppel, S., Laure Preterre, A., Iqbal, K., et al. (2018). Food groups and risk of colorectal cancer. *Int. J. Cancer* 142, 1748–1758. doi: 10.1002/ijc.31198

Segev, A., Badani, H., Kapulnik, Y., Shomer, I., Oren-Shamir, M., and Galili, S. (2010). Determination of polyphenols, flavonoids, and antioxidant capacity in colored chickpea (*Cicer arietinum* L.). *J. Food Sci.* 75, S115–S119. doi: 10.1111/j.1750-3841.2009.01477.x

Sehar, S., Rabail, R., Munir, S., Shakeel, K., Khalil, A. A., Tufail, T., et al. (2023). An insight into anticancer perspectives of chickpea bioactive compounds. *Food Chem. Adv.* 3:100453. doi: 10.1016/j.focha.2023.100453

Serna, J., and Bergwitz, C. (2020). Importance of dietary phosphorus for bone metabolism and healthy aging. *Nutrients* 12:3001. doi: 10.3390/nu12103001

Serventi, L., and Dsouza, L. V. (2020). Bioactives in legumes in upcycling legume water: From wastewater to food ingredients. Switzerland: Springer, 139–153.

Shahzad, A., Ullah, S., Dar, A. A., Sardar, M. F., Mehmood, T., Tufail, M. A., et al. (2021). Nexus on climate change: agriculture and possible solution to cope future climate change stresses. *Environ. Sci. Pollut. Res.* 28, 14211–14232. doi: 10.1007/s11356-021-12649-8

Sharma, S., and Singh, N. D. (2024). Enhancing chickpea (*Cicer arietinum* L.) production through front-line demonstration in submountainous region of Punjab, India. *J. Food Legume* 37, 95–100. doi: 10.59797/jfl.v37.i1.182

Shi, L., Arntfield, S. D., and Nickerson, M. (2018). Changes in levels of phytic acid, lectins and oxalates during soaking and cooking of Canadian pulses. *Food Res. Int.* 107, 660–668. doi: 10.1016/j.foodres.2018.02.056

Singh, J., and Basu, P. S. (2012). Non-nutritive bioactive compounds in pulses and their impact on human health: an overview. *Food Nutr. Sci.* 3, 1664–1672. doi: 10.4236/fns.2012.312218

Singh, B., Singh, J. P., Shevkani, K., Singh, N., and Kaur, A. (2017). Bioactive constituents in pulses and their health benefits. *J. Food Sci. Technol.* 54, 858–870. doi: 10.1007/s13197-016-2391-9

Singhal, S., Baker, R. D., and Baker, S. S. (2017). A comparison of the nutritional value of cow's milk and nondairy beverages. *J. Pediatr. Gastroenterol. Nutr.* 64, 799–805. doi: 10.1097/MPG.0000000000001380

Soares, P., Davó-Blanes, M. C., Martinelli, S. S., Melgarejo, L., and Cavalli, S. B. (2017). The effect of new purchase criteria on food procurement for the Brazilian school feeding program. *Appetite* 108, 288–294. doi: 10.1016/j.appet.2016.10.016

Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., et al. (2019). The global syndemic of obesity, undernutrition, and climate change: the lancet commission report. *Lancet* 393, 791–846. doi: 10.1016/S0140-6736(18)32822-8

Tabe-Ojong, M. P. J., Mausch, K., Woldeyohanes, T. B., and Heckelei, T. (2022). Three hurdles towards commercialisation: integrating subsistence chickpea producers in the market economy. *Eur. Rev. Agric. Econ.* 49, 668–695. doi: 10.1093/erae/jbab023

Tamang, J. P., Agahi, F., Yilmaz, B., Künili, İ. E., Mardon, J., Tüccar, T., et al. (2025). Characterization of fermented foods: bone health. *Front. Nutr.* 12:1648775. doi: 10.3389/fnut.2025.1648775

Timoracká, M., Snirc, M., Musilová, J., and Cicova, I. (2022). The variability of the total polyphenols content and the antioxidant activity in the varieties of selected legumes. *J. Microbiol. Biotechnol. Food Sci.* 12:e9399. doi: 10.55251/jmbfs.9399

Uriot, O., Defois-Fraysse, C., Couturier, I., Deschamps, C., Durif, C., Chaudemanche, C., et al. (2025). Effects of prebiotics from diverse sources on dysbiotic gut microbiota associated to western diet: insights from the human mucosal ARtificial COLon (M-ARCOL). *Curr. Res. Food Sci.* 10:100968. doi: 10.1016/j.crfs.2024.100968

U.S. Department of Agriculture (2018). USDA National Nutrient Database for standard reference legacy (2018). Available online at: https:// fdc.nal.usda.gov/food-details/173756/nutrients (Accessed September 20, 2025).

U.S. Department of Agriculture (2023). Food data central. Available online at: https://fdc.nal.usda.gov (Accessed September 20, 2025).

Veenstra, J. M., Duncan, A. M., Cryne, C. N., Deschambault, B. R., Boye, J. I., Benali, M., et al. (2010). Effect of pulse consumption on perceived flatulence and gastrointestinal function in healthy males. *Food Res. Int.* 43, 553–559. doi: 10.1016/j.foodres.2009.07.029

Vélez, M., Lazo, A., Caroca-Cáceres, R., and Peña, M. A. (2023). "Health benefits of chickpea and cowpea" in Chickpea and Cowpea. eds. S. Singh Purewal, P. Kaur and R. Kumar Salar (Boca Raton, FL and Oxon, OX: CRC Press), 301–331.

Vinod, B. R., Asrey, R., Rudra, S. G., Urhe, S. B., and Mishra, S. (2023). Chickpea as a promising ingredient substitute in gluten-free bread making: an overview of technological and nutritional benefits. *Food Chem. Adv.* 3:100473. doi: 10.1016/j.focha.2023.100473

Wallace, T. C., Murray, R., and Zelman, K. M. (2016). The nutritional value and health benefits of chickpeas and hummus. *Nutrients* 8:766. doi: 10.3390/nu8120766

Wang, X., Gao, W., Zhang, J., Zhang, H., Li, J., He, X., et al. (2010a). Subunit, amino acid composition and in vitro digestibility of protein isolates from Chinese "kabuli" and "desi" chickpea (*Cicer arietinum* L.) cultivars. *Food Res. Int.* 43, 567–572. doi: 10.1016/j.foodres.2009.07.018

Wang, N., Hatcher, D. W., Tyler, R. T., Toews, R., and Gawalko, E. J. (2010b). Effect of cooking on the composition of beans (*Phaseolus vulgaris* L.) and chickpeas (*Cicer arietinum* L.). *Food Res. Int.* 43, 589–594. doi: 10.1016/j.foodres.2009.07.012

Wang, S., Chelikani, V., and Serventi, L. (2018). Evaluation of chickpea as alternative to soy in plant-based beverages, fresh and fermented. *LWT Food Sci. Technol.* 97, 570–572. doi: 10.1016/j.lwt.2018.07.067

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. (2019). Food in the Anthropocene: the EAT–lancet commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. doi: 10.1016/S0140-6736(18)31788-4

Wood, J. A., and Grusak, M. A. (2007). "Nutritional value of chickpea" in Chickpea breeding and management. eds. S. S. Yadav, R. Redden, W. Chen and B. Sharma (UK: CABI Wallingford), 101–142.

Wood, J. A., Knights, E. J., and Choct, M. (2011). Morphology of chickpea seeds (*Cicer arietinum* L.): comparison of "desi" and "kabuli" types. *Int. J. Plant Sci.* 172, 632–643. doi: 10.1086/659456

Wu, A. H., Yu, M. C., Tseng, C. C., and Pike, M. C. (2008). Epidemiology of soy exposures and breast cancer risk. *Br. J. Cancer* 98, 9–14. doi: 10.1038/sj.bjc.6604145

Xiao, S., Li, Z., Zhou, K., and Fu, Y. (2022). Chemical composition of 'kabuli' and 'desi' chickpea (*Cicer arietinum* L.) cultivars grown in Xinjiang, China. *Food Sci. Nutr.* 11, 236–248. doi: 10.1002/fsn3.3056

Xue, Z., Wen, H., Zhai, L., Yu, Y., Li, Y., Yu, W., et al. (2015). Antioxidant activity and anti proliferative effect of a bioactive peptide from chickpea (*Cicer arietinum* L.). *Food Res. Int.* 77:75 81. doi: 10.1016/j.foodres.2015.09.027

Zafar, T. A., and Kabir, Y. (2017). Chickpeas suppress postprandial blood glucose concentration, and appetite and reduce energy intake at the next meal. *J. Food Sci. Technol.* 54, 987–994. doi: 10.1007/s13197-016-2422-6

Zewde, Y. W., and Fikre, A. (2019). The economics of targeting and sustaining a niche market: a case study of green pod chickpea marketing in Ethiopia. *J. Econ. Sustain. Dev.* 10, 40–52. doi: 10.7176/JESD/10-15-06

Zhang, Y., Su, D., He, J., Dai, Z., Asad, R., Ou, S., et al. (2017). Effects of ciceritol from chickpeas on human colonic microflora and the production of short chain fatty acids by in vitro fermentation. *LWT* 79, 294–299. doi: 10.1016/j.lwt.2017.01.040

Zhao, X., Sun, L., Zhang, X., Wang, M., Liu, H., and Zhu, Y. (2021). Nutritional components, volatile constituents and antioxidant activities of 6 chickpea species. *Food Biosci.* 41:100964. doi: 10.1016/j.fbio.2021.100964

Zhou, J., Li, M., Bai, Q., de Souza, T. S., Barrow, C., Dunshea, F., et al. (2024). Effects of different processing methods on pulses phytochemicals: an overview. *Food Rev. Int.* 40, 1138–1195. doi: 10.1080/87559129.2023.2212041

Zia-Ul-Haq, M., Iqbal, S., Ahmad, S., Imran, M., Niaz, A., and Bhanger, M. I. (2007). Nutritional and compositional study of "desi" chickpea (*Cicer arietinum* L.) cultivars grown in Punjab, Pakistan. *Food Chem.* 105, 1357–1363. doi: 10.1016/j.foodchem.2007.05.004