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Comparative Analysis of Anti-Nutritional Factors in Edible Legumes

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Abstract Edible legumes are rich in protein, dietary fiber, minerals and various functional active components, and are an important part of the global dietary structure. However, while these beans are providing nutritional value, they also contain a variety of anti-nutritional factors, such as phytic acid, oxalic acid, tannin, saponin, protease inhibitor and lectin, which may affect the absorption and utilization of key nutrients by the human body. This study systematically reviewed the types of common anti-nutritional factors in edible legumes, their physiological mechanisms of action, and the distribution patterns of their contents in different legumes (such as soybeans, mung beans, peas, red adzuki beans, kidney beans, and chickpeas), analyzed their interactions with nutritional components, and explored their possible positive physiological functions. The research progress of traditional and modern detoxification treatment technologies (such as fermentation, enzyme treatment, genetic modification, etc.) was also reviewed, and the practical experiences of different countries and regions in the control of anti-nutritional factors were discussed. Through in-depth comparisons of the composition, functional effects and treatment strategies of anti-nutritional factors, this study aims to provide scientific basis and technical references for the nutritional optimization, variety breeding and functional product development of edible legumes, and promote the sustainable utilization and value enhancement of legumes in the fields of food and health.

Keywords Edible beans; Anti-nutritional factors; Nutritional interaction; Processing technology; Comparative analysis

1 Introduction

Beans are not just side dishes in many places; they are often the "main force" on the dining table. What does it rely on? On the one hand, they are rich in protein, dietary fiber, essential amino acids, vitamins and various minerals, and are indeed nutritionally comprehensive. For many low-income families, beans are one of the few affordable high-protein sources (Banti and Bajo, 2020; Jha et al., 2022). In addition, they contain a considerable amount of phytochemicals, such as polyphenols and saponins, which not only provide nutritional supplements but may also be beneficial to health (Samtiya et al., 2020). So from traditional diets to modern nutrition science, they have never been neglected.

But then again, beans are not "flawless" either. They naturally carry some less "friendly" components in their bodies, such as phytic acid, tannin, saponin, lectin, protease inhibitor, amylase inhibitor, and oligosaccharides, especially the raffinose group (Elango et al., 2022). Overall, these things are not fatal, but they do "hinder" nutrient absorption: either they reduce the digestibility of protein or they compete with minerals like iron, zinc, and calcium for resources. In severe cases, they can cause bloating, gastrointestinal discomfort, and even poisoning (Dangi et al., 2021). Although some studies have shown that some ANF has positive effects such as antioxidation at low concentrations, most of the time, people are still more concerned about how to control these "side effects" in order to truly bring out the nutritional potential of beans.

This study systematically compared the types and levels of anti-nutritional factors in major edible legumes, explored their physiological effects, reviewed current strategies for reducing these factors, clarified the diversity and mechanism of action of anti-nutritional factors, evaluated their impacts on human health and nutrition, and focused on introducing effective processing or breeding methods to mitigate their negative effects. By providing a comprehensive comparative analysis, this study aims to offer references for dietary recommendations, support leguminous breeding programs, and promote the safe and effective use of legumes in global diets.

2 Types and Biological Functions of Common Anti-Nutritional Factors

2.1 Inhibitory effects of phytates and oxalates on mineral absorption

Not all minerals can be smoothly absorbed by the human body. Sometimes the problem lies in certain natural components in the beans. For instance, phytic acid, which is very common in beans, easily combines with minerals such as calcium, iron, zinc and copper to form insoluble complexes. As a result, the body has difficulty absorbing these nutrients (Nkhata et al., 2018). Oxalic acid is also a "troublemaker", especially hindering calcium absorption and may also increase the risk of kidney stones (Jha et al., 2022). For some people who mainly rely on a plant-based diet, these factors are very likely to be one of the root causes of micronutrient deficiencies.

2.2 Inhibitory mechanisms of protease inhibitors and trypsin inhibitors

Some people think that eating bean protein can easily absorb it, but that's not the case. Some anti-nutritional factors - such as protease inhibitors, especially trypsin inhibitors - can interfere with the activity of digestive enzymes. For instance, trypsin and chymotrypsin, which are the "main decomposition forces", are "entangled" by them, thereby reducing the digestibility of proteins (Dangi et al., 2021). In populations where protein sources are already scarce, this inhibition may lead to growth restriction. But the good news is that most of these inhibitors are not heat-resistant, and their content can be significantly reduced after cooking or processing.

2.3 Effects of tannins, saponins, and lectins on the digestive and absorptive systems

Tannins, saponins and lectin, these names that sound quite "chemical", are actually hidden in many common beans. Tannin is a type of polyphenolic compound that can combine with proteins and digestive enzymes, reducing the digestibility of proteins and also affecting the absorption of minerals such as iron (Samtiya et al., 2020). The function of saponins is slightly more complex. They can form complexes with proteins and cholesterol. In severe cases, they may even damage cell membranes and cause gastrointestinal discomfort. Lectin, also known as phytohemagglutinin, is a carbohydrate that directly adheres to the intestinal wall cells, affecting the absorption system (Banti and Bajo, 2020). Of course, if the intake is only low, the situation is not serious. There are also studies that have found that these substances have the potential to act as antioxidants and even fight cancer at low doses. The problem is that when beans become the staple food, their side effects can no longer be ignored.

3 Comparative Analysis of Anti-Nutritional Factor Contents in Different Legumes

3.1 Analysis of major anti-nutritional components in soybean, mung bean, and pea

Although all beans are rich in plant protein, the content of anti-nutritional factors (ANF) varies. Take soybeans as an example. The levels of phytic acid and trypsin inhibitors are not low, which is why it is often pointed out to affect protein digestion and mineral absorption (Samtiya et al., 2020). The situation of mung beans is slightly better. Although they also contain phytic acid and tannin, some genotypes with low content have been identified through selection and breeding (Sinha et al., 2023). The advantage of peas lies in the fact that they have relatively little ANF (especially tannin) to start with, so they are considered one of the more suitable raw materials for food or feed, especially after breeding improvement (Miki et al., 2009).

3.2 Composition characteristics of anti-nutritional factors in adzuki bean, kidney bean, and chickpea

Not all beans are on the same starting line in terms of nutritional safety. For instance, kidney beans are rather "troublesome" due to their high content of lectin and phytic acid - if not handled properly, they not only affect absorption but may also cause toxic reactions (Venketeish et al., 2024). In contrast, chickpeas have a moderate level of anti-nutritional substances. Besides phytic acid, saponins and oligosaccharides, some varieties are even rich in vitamin E (Banti and Bajo, 2020). As for red adzuki beans, although there are relatively few studies on them, preliminary results show that their phytic acid, tannin and saponin contents are generally lower than those of kidney beans. As part of dietary diversification, they have potential to be explored.

3.3 Impact of varieties, origins, and cultivation practices on anti-nutritional factor content

The content of ANF in the same kind of bean may vary when grown in different places. In fact, not only the geographical environment but also the cultivation methods and the varieties themselves can affect the final component levels. For crops like chickpeas or lentils, the differences in phytochemical content among different

genotypes can sometimes be significant (Myrtsi et al., 2024). This is also why the analysis of variety differences is always inevitable in the selection and breeding work. At present, some representative achievements have been made, such as the emergence of low-ANF varieties like Kunitz-free soybeans and zero-tannin peas, with the aim of enhancing nutritional quality and safety (Jha et al., 2022). In addition, environmental conditions and management measures cannot be ignored either, as they also have a considerable impact on the accumulation of nutrients in seeds.

4 Interactions Between Anti-Nutritional Factors and Nutrients

4.1 Binding mechanisms between anti-nutrients and proteins, minerals, and vitamins

Anti-nutritional factors (ANF) are not always "poisons", but they do interfere with the normal utilization of nutrients by the human body. Common ANF substances like phytic acid, tannin and oxalic acid tend to get entangled with minerals (such as calcium, iron, zinc and copper) and proteins in the intestines, forming complexes that are not easily absorbed. The result is that the nutrients ingested are not truly absorbed. Phytic acid sometimes even affects the function of vitamin D, and components like avidin can "bind" biotin, directly influencing the availability of vitamins (Arsov et al., 2024; Gao and Li, 2025). These reactions themselves are not uncommon, but the severity of the problem can vary depending on the diet structure.

4.2 Inhibitory effects on the bioavailability of micronutrients

Not all the nutrients in beans can be easily absorbed, especially trace elements like iron and zinc, which are more likely to be "locked" in foods with high phytic acid and polyphenol content. This kind of situation is particularly common in regions that rely mainly on plants such as beans as their food sources, and sometimes it can develop into micronutrient deficiencies (Raes et al., 2014). In addition, components such as protease inhibitors and lectins not only affect the decomposition and absorption of proteins but also indirectly drag down the absorption efficiency of other nutrients, such as amino acids (Figure 1) (Nkhata et al., 2018; Kong et al., 2022). Although the body has certain regulatory mechanisms, long-term intake of a diet high in ANF is indeed a hidden danger.

4.3 Potential positive roles: antioxidant and anti-cancer properties

However, anti-nutritional factors (ANF) cannot be completely dismissed. Studies have found that components such as phytic acid, tannin, and saponin may actually be beneficial at low concentrations. Their antioxidant activity, metal chelating effect and even certain anti-cancer potential have been demonstrated in some animal experiments and cell-level studies (Gemede and Ratta, 2014; Samtiya et al., 2020; Salim et al., 2023). These compounds have also been observed to potentially regulate blood sugar, cholesterol and insulin responses. Therefore, ANF is sometimes like a double-edged sword. While it interferes with nutrient absorption, it also offers potential protective effects.

5 Traditional and Modern Technologies to Eliminate or Reduce Anti-Nutritional Factors

5.1 Traditional processing methods: soaking, germination, cooking, and fermentation

Many families have long adopted some actually very effective methods to lower ANF (anti-nutritional factor) when dealing with beans, such as soaking, germination, cooking and fermentation. These may seem like "old ways", but they do work. Soaking and germination are not only for shortening the cooking time, but also can activate the enzymes inside the beans, especially phytase, which helps break down phytic acid and other harmful factors, while also filtering out some water-soluble components (Amoah et al., 2023). High-temperature cooking, especially when there is a lot of water, is relatively direct in dealing with heat-unstable factors such as trypsin inhibitors and lectins (Gbedo et al., 2024). Fermentation is more complex, and the effects of different strains vary. However, commonly used strains such as lactic acid bacteria and Bacillus show stable performance in decomposing saponins, tannins, phytic acid and oligosaccharides, sometimes with a reduction of 60% to 90%, which depends on the specific process and the type of legume (De Pasquale et al., 2019; Sakandar et al., 2021). To further enhance the processing effect, it is also common to combine several methods, such as germination followed by fermentation (Nkhata et al., 2018).

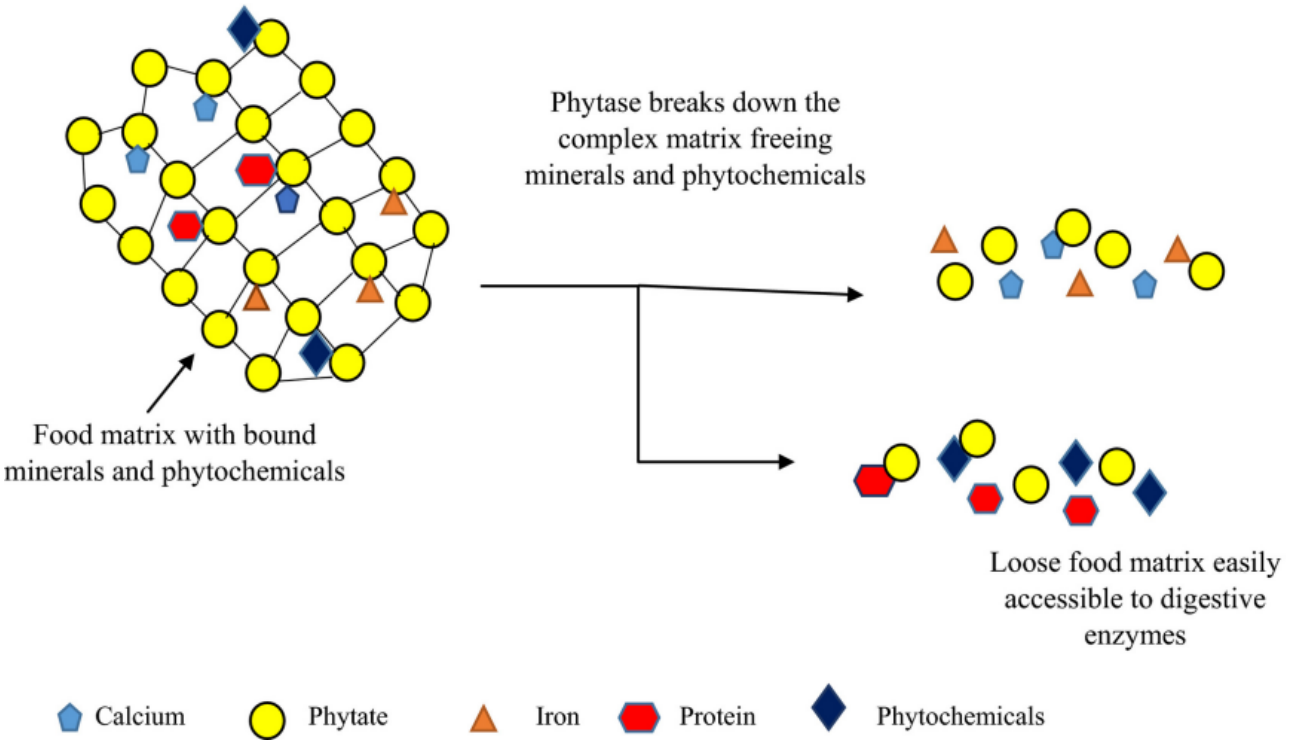

Figure 1 Plausible mechanism by which fermentation leads to increased minerals, phytochemicals, and proteins bioavailability (Adopted from Nkhata et al., 2018)

5.2 Modern detoxification techniques: enzymatic treatment, ultrasound, and high-pressure processing

Traditional methods rely on time and temperature, but modern technology takes a more "shortcut". Nowadays, there are some emerging processing methods that emphasize efficiency and are more targeted. For instance, when exogenous enzymes are directly added for treatment, phytase is a typical representative. It mainly helps break down phytic acid and enhance the absorption rate of minerals such as iron and zinc (Das et al., 2022). There are also physical methods such as ultrasonic or high-pressure treatment, whose core principle is to disrupt the cell structure and denature proteins incidentally. The result is that substances like trypsin inhibitors and lectins are significantly weakened, but nutrition is not necessarily impaired as a result (Gharibzahedi and Smith, 2020). In addition, methods such as extrusion, microwave, and irradiation are also quite common, among which extrusion is particularly frequently used. It not only continuously and rapidly decomposes ANF but also enhances the functionality of soybean flour (Nikmaram et al., 2017; Ozolina et al., 2023). However, these methods do not exist in isolation. Only when combined with traditional techniques can they achieve the greatest benefits.

5.3 Application of genetic improvement and molecular breeding in anti-nutrient control

Starting from the source might be more effective than handling it later. To make the beans themselves "less problematic", scientists are also making efforts in breeding. Varieties like Kunitz-free soybeans, low-phytic acid chickpeas, and zero-tannin peas are no longer laboratory concepts but the results of breeding efforts combined with marker selection, genomic analysis, and even CRISPR editing techniques (Miki et al., 2009). The goal of breeding is not simply to "reduce ANF", but to accurately identify their synthetic pathways, precisely carry out "deletion", while maintaining yield and other agronomic traits (Jha et al., 2022; Wu et al., 2024). Although this approach takes a long time to show results, it is stable and sustainable. It is still a worthwhile investment path for addressing long-term nutritional challenges.

6 Case Studies: Practices in Anti-Nutritional Factor Reduction in Legume-Based Products

6.1 Control strategies in the legume food industry (e.g., soy milk, Tofu)

When making soy milk or tofu, heat treatment is almost an indispensable step, and this step has actually long been used to control anti-nutritional factors (ANF). Processes such as boiling, extrusion, and autoclaving not only

ensure food safety but also incidentally handle heat-sensitive substances like trypsin inhibitors and lectins (Ozolina et al., 2023). However, heat treatment is not the only option. Fermentation is also very common, especially when it comes to improving taste or adding functional components. Using lactic acid bacteria for fermentation can effectively reduce the content of phytic acid, oligosaccharides and tannins, and the absorption rate of nutrients will also increase accordingly. In fact, some processes are mixed and combined, such as soaking first and then steaming, or adding a fermentation step to balance processing efficiency and the effect of anti-nutritional factor degradation as much as possible (Nikmaram et al., 2017). In industry, the pursuit is large-scale processing, so these processes are constantly optimized and combined to adapt to different product lines and nutritional requirements.

6.2 Traditional anti-nutrient reduction practices in countries like India, Nigeria, and China

Some practices predate modern industry much earlier, but they are just not classified as "science". In countries with high consumption of beans such as India, Nigeria or China, people have long mastered through experience how to deal with such "somewhat obstructive" components. The common methods used in Indian households are soaking or sprouting, which are indeed effective in reducing phytic acid and enzyme inhibitors. Many home-cooked bean dishes are processed in this way. The fermentation process, similar to that of dosa or idli, actually simultaneously decomposes anti-nutritional factors (Anaemene and Fadupin, 2022; Venketeish et al., 2024). Nigeria, on the other hand, prefers natural fermentation methods, with wood beans and soybeans being the most commonly used. Some data even show that the reduction in phytic acid and tannin can reach over 90%, and it can also improve protein digestibility (Adeyemo and Onilude, 2013). In China, traditional methods such as soaking beans and simmering them over low heat actually follow a similar nutritional logic: they not only aim for a soft and glutinous texture but also subtly address the issue of ANF (Kong et al., 2022).

6.3 Breeding of low anti-nutrient varieties and development of functional legume products

To solve problems from the source, breeding is an inevitable path. The current market products such as Kurnitz soybeans, low-phytic acid chickpeas, and zero-tannin peas are all achievements of molecular breeding technology (Miki et al., 2009). Some of them employed traditional breeding methods, while many others relied on marker-assisted breeding or gene editing techniques to directly "subtract" from the ANF synthesis pathway (Figure 2) (Jha et al., 2022). The benefits of this variety are obvious: the processing is more convenient and the bioavailability of nutrients can also be significantly improved. It is a plus for both public health and the development of functional foods. As consumers' calls for "healthier plant protein" grow louder, these low-ANF raw materials are gradually moving out of the research stage and entering true market application.

7 Conclusion and Outlook

Researchers have generally noted that anti-nutritional factors (ANF) present in legumes, such as phytic acid, tannins, saponins and protease inhibitors, do indeed make some key nutrients more difficult for the human body to absorb. Especially in a diet dominated by plant-based foods, such substances may become triggers for micronutrient deficiencies, affecting health conditions. However, we cannot simply deny their significance of existence. Components like saponins and tannins have instead demonstrated antioxidant and anti-cancer potential in some studies, and plants themselves rely on these substances to defend against adverse conditions or pests. The current issue is not whether to "eliminate" them or not, but rather how to minimize their negative impacts while preserving their benefits for health and agronomy.

Next, the research direction may no longer be confined to a single technology. The combination of multi-omics approaches - such as genomics, transcriptome analysis and gene editing - is increasingly being used to breed new varieties of legumes that are both nutritionally rich and can reduce ANF content. However, in practice, it is hard to avoid the situation where "one hair moves and the whole body is affected". For instance, when certain anti-nutritional substances are reduced, it may also affect the quality or yield of seeds. Therefore, how to keep these side effects within a reasonable range is a problem that must be considered during breeding. Furthermore, some institutional issues remain unclear, such as how exactly does ANF affect nutrient absorption? Which

nutrients may it have a synergistic or antagonistic effect with in the human body? Such issues require interdisciplinary collaboration to advance, providing a more solid scientific foundation for the development of functional foods and health products.

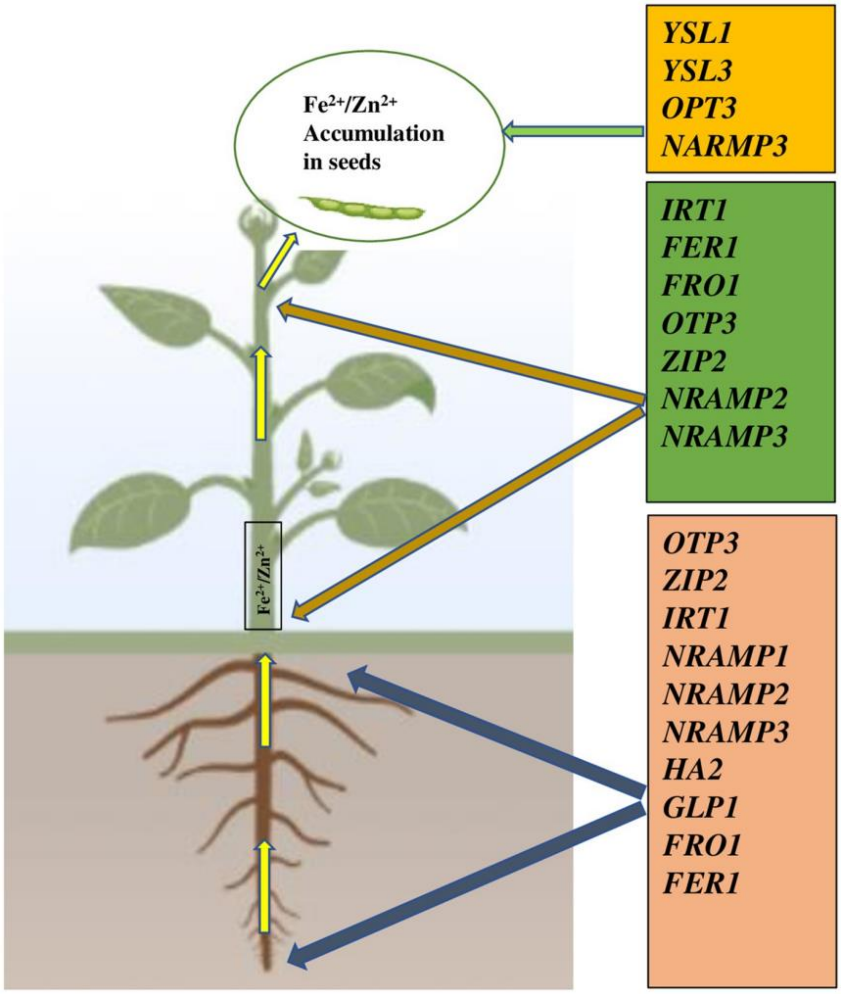

Figure 2 Gene families involved in translocation and accumulation of Fe^{2+}/Zn^{2+} in seed of common bean. *YSL1* and *YSL3* genes are involved in unloading minerals to seeds. YSL, Yellow Stripe Like; OPT, Oligopeptide transporter; NRAMP, Natural resistance-associated macrophage protein; IRT, Iron regulated transporter; FER, Ferritin; FRO Ferric reduction oxidase; ZIP, Zinc induced protein; HA, H+ transporting ATPase; GLP, Germin like protein. Plant images made with Biorender (https://biorender.com/) (Adopted from Jha et al., 2022)

From the perspective of application, there is actually still a lot of room for improvement in legumes. Current molecular breeding and back-end processing technologies can already support the development of varieties with low ANF and high nutritional value, and metabolomics also provides new tools for component tracking and precise regulation. In the future, we may witness the emergence of more legumes that are safer and more nutritionally comprehensive. It is not just about supplementing staple foods. They are also expected to offer multiple solutions to malnutrition problems, food security challenges, and the sustainable development of agriculture. Especially those leguminous resources that have not yet been widely utilized, if they can play a role in food diversity, may also become "potential stocks" in the global nutrition system.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Abbas Y., and Ahmad A., 2018, Impact of processing on nutritional and antinutritional factors of legumes: a review, Food Science & Technology, 19(2): 199.

Adeyemo S., and Onilude A., 2013, Enzymatic reduction of anti-nutritional factors in fermenting soybeans by *Lactobacillus plantarum* isolates from fermenting cereals, Nigerian Food Journal, 31(2): 84-90.
https://doi.org/10.1016/S0189-7241(15)30080-1

Amoah I., Ascione A., Muthanna F., Feraco A., Camajani E., Gorini S., Armani A., Caprio M., and Lombardo M., 2023, Sustainable strategies for increasing legume consumption: culinary and educational approaches, Foods, 12(11): 2265.
https://doi.org/10.3390/foods12112265

Anaemene D., and Fadupin G., 2022, Anti-nutrient reduction and nutrient retention capacity of fermentation, germination and combined germination-fermentation in legume processing, Applied Food Research, 2(1): 100059.
https://doi.org/10.1016/j.afres.2022.100059

Arsov A., Tsigoriyna L., Batovska D., Armenova N., Mu W., Zhang W., Petrov K., and Petrova P., 2024, Bacterial degradation of antinutrients in foods: the genomic insight, Foods, 13(15): 2408.
https://doi.org/10.3390/foods13152408

Banti M., and Bajo W., 2020, Review on nutritional importance and anti-nutritional factors of legumes, International Journal of Nutrition and Food Sciences, 9: 138.
https://doi.org/10.11648/J.IJNFS.20200906.11

Dangi P., Chaudhary N., Gajwani D., and Neha, 2021, Antinutritional factors in legumes, Handbook of Cereals, Pulses, Roots, and Tubers, 20: 14.
https://doi.org/10.1201/9781003155508-20

Das G., Sharma A., and Sarkar P., 2022, Conventional and emerging processing techniques for the post-harvest reduction of antinutrients in edible legumes, Applied Food Research, 2(1): 100112.
https://doi.org/10.1016/j.afres.2022.100112

De Pasquale I., Pontonio E., Gobbetti M., and Rizzello C., 2019, Nutritional and functional effects of the lactic acid bacteria fermentation on gelatinized legume flours, International Journal of Food microbiology, 316: 108426.
https://doi.org/10.1016/j.ijfoodmicro.2019.108426

Elango D., Rajendran K., Van Der Laan L., Sebastiar S., Raigne J., Thaiparambil N., Haddad N., Raja B., Wang W., Ferela A., Chiteri K., Thudi M., Varshney R., Chopra S., Singh A., and Singh A., 2022, Raffinose family oligosaccharides: friend or foe for human and plant health? Frontiers in Plant Science, 13: 829118.
https://doi.org/10.3389/fpls.2022.829118

Gao H.T., and Li H.Y., 2025, Marker-assisted selection (MAS) in soybean breeding, Molecular Plant Breeding, 16(1): 35-43.
https://doi.org/10.5376/mpb.2025.16.0004

Gbedo C., Arnaud E., and Strub C., 2024, Traditional legume seed fermentation processes: what is the individual impact of the cooking and fermentation stages on the degradation of anti-nutritional factors? Food Reviews International, 41(5): 1290-1320.
https://doi.org/10.1080/87559129.2024.2430653

Gemede H., and Ratta N., 2014, Antinutritional factors in plant foods: potential health benefits and adverse effects, International Journal of Nutrition and Food Sciences, 3: 284.
https://doi.org/10.11648/J.IJNFS.20140304.18

Gharibzahedi S., and Smith B., 2020, Effects of high hydrostatic pressure on the quality and functionality of protein isolates, concentrates, and hydrolysates derived from pulse legumes: a review, Trends in Food Science & Technology, 107: 466-479.
https://doi.org/10.1016/j.tifs.2020.11.016

Jha R., Yadav H., Raiya R., Singh R., Jha U., Sathee L., Singh P., Thudi M., Singh A., Chaturvedi S., and Tripathi S., 2022, Integrated breeding approaches to enhance the nutritional quality of food legumes, Frontiers in Plant Science, 13: 984700.
https://doi.org/10.3389/fpls.2022.984700

Kong X., Li Y., and Liu X., 2022, A review of thermosensitive antinutritional factors in plant-based foods, Journal of Food Biochemistry, 46(9): e14199.
https://doi.org/10.1111/jfbc.14199

Mikić A., Perić V., Đorđević V., Srebrić M., and Mihailović V., 2009, Anti-nutritional factors in some grain legumes, Biotechnology in Animal Husbandry, 25: 1181-1188.

Myrtsi E., Vlachostergios D., Petsoulas C., Koulocheri S., Evergetis E., and Haroutounian S., 2024, Eleven greek legume beans: assessment of genotypic effect on their phytochemical content and antioxidant properties, Antioxidants, 13(4): 459.
https://doi.org/10.3390/antiox13040459

Nikmaram N., Leong S., Koubaa M., Zhu Z., Barba F., Greiner R., Oey I., and Roohinejad S., 2017, Effect of extrusion on the anti-nutritional factors of food products: an overview, Food Control, 79: 62-73.
https://doi.org/10.1016/J.FOODCONT.2017.03.027

Nkhata S., Ayua E., Kamau E., and Shingiro J., 2018, Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes, Food Science & Nutrition, 6(8): 2446-2458.
https://doi.org/10.1002/fsn3.846

Ozolina K., Sarenkova I., and Muižniece-Brasava S., 2023, The anti-nutritional factors of legumes and their treatment possibilities: a review, Research for Rural Development, 38: 68-76.
https://doi.org/10.22616/rrd.29.2023.010

Raes K., Knockaert D., Struijs K., and Camp J., 2014, Role of processing on bioaccessibility of minerals: influence of localization of minerals and anti-nutritional factors in the plant, Trends in Food Science and Technology, 37(1): 32-41.
https://doi.org/10.1016/J.TIFS.2014.02.002

Sakandar H., Chen Y., Peng C., Chen X., Imran M., and Zhang H., 2021, Impact of fermentation on antinutritional factors and protein degradation of legume seeds: a review, Food Reviews International, 39(3): 1227-1249.
https://doi.org/10.1080/87559129.2021.1931300

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

Samtiya M., Aluko R., and Dhewa T., 2020, Plant food anti-nutritional factors and their reduction strategies: an overview, Food Production, Processing and Nutrition, 2: 6.
https://doi.org/10.1186/s43014-020-0020-5

Sharma A., 2020, A review on traditional technology and safety challenges with regard to antinutrients in legume foods, Journal of Food Science and Technology, 58: 2863-2883.
https://doi.org/10.1007/s13197-020-04883-8

Sinha M., Aski M., Mishra G., Kumar M., Yadav P., Tokas J., Gupta S., Pratap A., Kumar S., Nair R., Schafleitner R., and Dikshit H., 2023, Genome wide association analysis for grain micronutrients and anti-nutritional traits in mungbean [*Vigna radiata* (L.) R. Wilczek] using SNP markers, Frontiers in Nutrition, 10: 1099004.
https://doi.org/10.3389/fnut.2023.1099004

Venketeish K., Govindarajan N., Pandiselvam R., and Khaneghah A., 2024, Unlocking the potential of underutilized legumes: nutritional benefits, anti-nutritional challenges, and mitigation strategies, Journal of Food Measurement and Characterization, 18: 9588-9602.
https://doi.org/10.1007/s11694-024-02905-z

Wu C.X., Yu D.M., and Qiu L.J., 2024, Molecular breeding for pest and disease resistance in legumes, Plant Gene and Trait, 15(4): 195-206.
https://doi.org/10.5376/pgt.2024.15.0020