PLANT SCIENCE TODAY
Vol 13(sp9): 1–11
https://doi.org/10.14719/pst.16563

eISSN 2348-1900
OPEN ACCESS

Review Article | Agriculture
2026, Volume 13, Issue sp9, pp. 1-11

Antinutritional factors in agricultural and horticultural crops: Occurrence, mechanisms and mitigation strategies—A narrative review

M Meera[1], R Nageswari[2*], G Prabu Kumar[1], P Malathi[3], R Poorniammal[4], R Kalpana[1] & R Anitha[5*]

[1]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Department of Agronomy, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Trichy 620 027, Tamil Nadu, India

[3]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[4]Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[5]Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

***Correspondence:** nageswari.r@tnau.ac.in; anitha.r@tnau.ac.in

Abstract

Antinutritional factors (ANFs) are naturally occurring bioactive compounds present in plant-based foods such as cereals, legumes and oilseeds. Antinutritional factors are often concentrated in specific plant parts such as the seed coat, bran, husk or outer grain layers. These include phytates, tannins, lectins, protease inhibitors, oxalates, saponins and cyanogenic glycosides, which can interfere with nutrient digestion, absorption and utilisation. Their levels vary greatly depending on species, genotype, environmental conditions and agronomic factors. At high concentrations, ANFs can cause mineral deficiencies, impair protein digestibility and negatively affect the growth and health of humans and animals. Antinutritional factors hinder processes such as nutrient absorption, respiratory function and iodine uptake and can increase intestinal permeability, leading to decreased absorption of iron (Fe), zinc (Zn) and calcium (Ca) in humans and to mineral deficiencies, stunted growth, kidney stones, Ca deficiency and urinary calculi. However, recent studies highlight their dual role, showing that moderate levels exhibit beneficial effects such as reducing oxidative stress and exhibiting anti-inflammatory, immunomodulatory and anticancer properties. The occurrence and concentration of ANFs vary depending on crop species, plant parts and environmental conditions. Various processing methods, including soaking, fermentation, germination and thermal treatments, effectively reduce ANF levels and improve nutrient availability. In addition, agronomic, genetic and biotechnological approaches offer promising strategies for regulating ANFs in crops. Therefore, a balanced approach focusing on modulation rather than complete elimination is essential for enhancing nutritional quality and ensuring food and nutritional security.

Keywords: agricultural crops; antinutritional factors; horticultural crops; mitigation strategies

Received: 06 July 2026. **Accepted:** 14 September 2026. **Available online:** Version 1.0: 18 November 2026.

Cite this article: Meera M, Nageswari R, Prabu KG, Malathi P, Poorniammal R, Kalpana R, Anitha R. Antinutritional factors in agricultural and horticultural crops: Occurrence, mechanisms and mitigation strategies—A narrative review. Plant Science Today. 2026; 13(sp9): 1-11. https://doi.org/10.14719/pst.16563

Introduction

Plants and their derivatives are the primary sources of nutrients for humans and animals. They are extensively utilised for medicinal purposes in addition to their nutritional value (1). Depending on their concentration levels, these compounds exert both beneficial and detrimental effects (2). They are mainly secondary metabolites (3) and encompass a wide array of chemical classes, including phytates, oxalates, tannins, saponins, lectins, protease and amylase inhibitors, cyanogenic glycosides, goitrogens, alkaloids and enzymes such as urease and lipoxygenase (4). Plants produce antinutritional factors (ANFs) as defence mechanisms against insects, pathogens and herbivores and they are particularly prevalent in legumes (soybean and chickpea), cereals (wheat, kodo millet and proso millet), nuts (walnut, cashew and almond), seeds (sesame and flax), certain roots (sweet potato and tapioca) and leafy vegetables (amaranth and nightshade) (3). The ANFs are bioactive substances (5) that interfere with the digestion, uptake and utilisation of nutrients (6) in both humans and monogastric animals (7).

However, the harmful effects of ANFs heavily depend on factors such as age, species, concentration, food processing and interaction with other nutrients. Recent research reveals the wide-ranging biological activities and potential health benefits of ANFs (8). At high concentrations, ANFs can affect the bioavailability of nutrients, thereby causing protein-energy malnutrition, reduced growth and poor health outcomes (9). In

contrast, at moderate concentrations, they show several beneficial effects such as antioxidants, anti-inflammatory, anti-obesity, cholesterol-lowering, blood glucose-reducing and potential anti-cancer properties (10). Therefore, antinutritional factors are not inherently harmful; their action and effects depend upon the digestive capacity of the consuming animal and the dietary context.

Antinutritional factors are of particular concern in areas that heavily rely on plant-based foods as staples and where micronutrient deficiencies are prevalent (11). The complete removal of antinutritional factors is neither possible nor desirable. Many strategies have been employed to reduce their effects in foods (12). The dual nature of ANFs demands carefully optimised processing methods that reduce adverse levels without completely removing the health-promoting compounds. Effective management aims to reduce the detrimental effects of ANFs while retaining their potential health benefits, thereby strengthening nutritional security worldwide (13).

In this narrative review, efforts were made to categorise the occurrence, roles and classification and effects of ANFs, not only their dark side but also their usefulness at possible ends. Furthermore, various findings on ANFs were documented as an analysis of the implications of ANFs produced by major agricultural and horticultural crops to gain a comprehensive understanding of ANFs. The literature was collected from the principal studies carried out on ANFs and published in leading journals of global importance for at least the past four decades. An attempt was made to create an accessible understanding of the subject by creating relevant images using the Canva tool.

Occurrence of antinutritional factors in crops

Antinutritional factors are naturally occurring compounds widely distributed in agricultural and horticultural crops (14). They are commonly found in pulses and legumes, followed by cereal grains and oilseeds, with pulses and legumes considered the richest sources of ANFs (15). Antinutritional factors are often concentrated in specific plant parts such as the seed coat, bran, husk or outer grain layers (Table 1, Fig. 1) (4). Their levels vary greatly depending on species, genotype, environmental conditions and agronomic factors (Fig. 2) (16).

Table 1. Major antinutritional factors present in different plants

Sl. No.	Crop	Location in plant/crop	Major antinutritional factors	References
1.	Rice	Bran/aleurone layer Seed coat (coloured rice)	Phytates, tannins (in pigmented rice), trypsin inhibitors (low)	(4, 17)
2.	Wheat	Bran/aleurone layer Germ	Phytates, tannins (bran), lectins, enzyme inhibitors	(4, 18)
3.	Maize	Germ Pericarp/seed coat	Phytates, tannins (coloured varieties), low lysine protein (zein)	(4)
4.	Sorghum	Seed coat (Testa) Aleurone layer	Tannins, phytates (low digestibility protein)	(19)
5.	Pearl millet	Mainly outer layers (bran/seed coat)	Phytates, tannins, polyphenols	(4)
6.	Finger millet	Seed coat and aleurone layer	Phytates, tannins, oxalates	(4)
7.	Green gram	Cotyledons Seed coat	Phytates, tannins, trypsin inhibitors, lectins	(4, 17)
8.	Black gram	Seed coat Cotyledons	Phytates, tannins, protease inhibitors	(4)
9.	Chickpea	Cotyledons Seed coat Seed surface	Phytates, tannins, saponins, protease inhibitors	(18)
10.	Pigeon pea	Seed coat Cotyledons	Phytates, tannins, trypsin inhibitors	(17)
11.	Soybean	Cotyledons Protein bodies in cotyledons	Trypsin inhibitors, lectins, phytates, saponins, goitrogens	(17)
12.	Groundnut	Seed coat Cotyledons	Phytates, tannins, trypsin inhibitors	(18)
13.	Rapeseed/ Mustard	Seed Cotyledons	Glucosinolates, erucic acid, phytates	(20)
14.	Cassava	Tuber cortex and leaves	Cyanogenic glycosides (linamarin), phytates	(21)
15.	Sweet potato	Tuber tissues and leaves	Oxalates, trypsin inhibitors	(4)
16.	Spinach	Leaves	Oxalates, nitrates	(22)
17.	Amaranth	Leaves Seed coat	Oxalates, saponins, nitrates	(4)

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

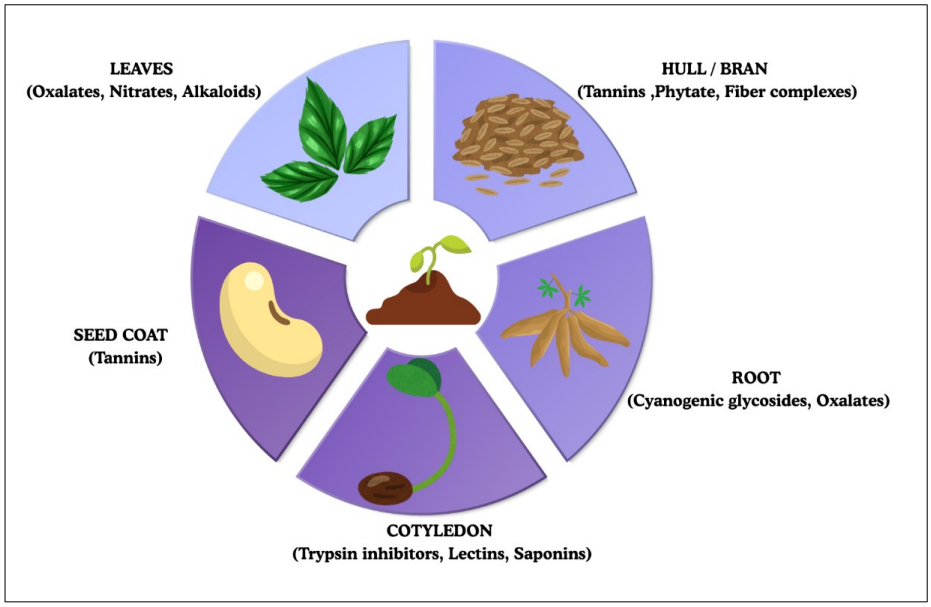


Fig. 1. Localisation of antinutritional factors in plant organs.

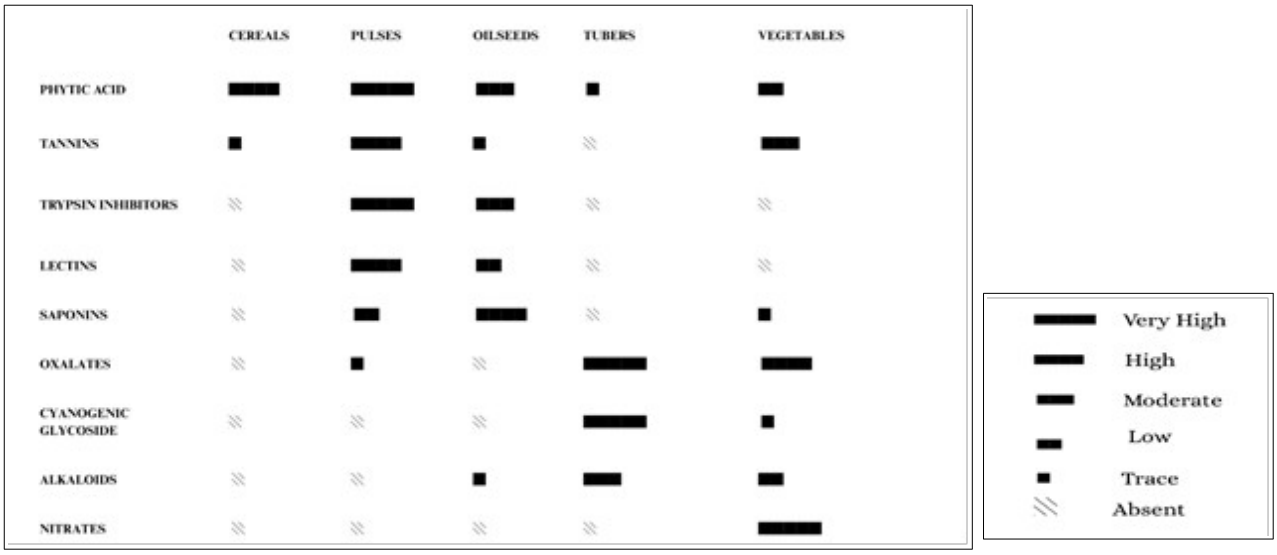


Fig. 2. Distribution pattern of antinutritional factors among crop groups.

Mechanism of action of antinutritional factors

Antinutritional factors have different mechanisms of action (Fig. 3). Phytic acid is the principal storage form of phosphorus (P) in cereals, legumes and oilseeds and it represents one of the most studied antinutritional compounds. Phytates contain negatively charged groups in their structure that bind with positively charged mineral cations, forming insoluble complexes that resist intestinal absorption. This chelation considerably reduces mineral bioavailability, particularly iron absorption in plant-based diets (23). Phytates also reduce protein and starch digestibility by binding with digestive enzymes such as trypsin and amylase.

Lectins, which are abundantly present in legumes and certain cereals, are carbohydrate-binding proteins (13). Lectins bind to epithelial cells in the intestine, disturb membrane integrity and thereby impair nutrient absorption (24). Lectins are also known as phytohemagglutinins because they can agglutinate red blood cells (14).

Tannins are phenolic compounds widely distributed in cereals, legumes, fruits and beverages (25). Tannins reduce protein digestibility by binding to and precipitating dietary proteins. In addition, tannins bind to essential micronutrients, forming insoluble complexes that make them unavailable to the body (13).

Cyanogenic glycosides are commonly found in crops such as cassava, lima beans and certain nuts (26). When tissue disruption occurs, endogenous β-glucosidase enzymes are activated, hydrolysing cyanogenic glycosides to release hydrogen cyanide. Hydrogen cyanide is highly poisonous, blocking cellular respiration and ATP production by inhibiting cytochrome c oxidase in mitochondria (14).

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

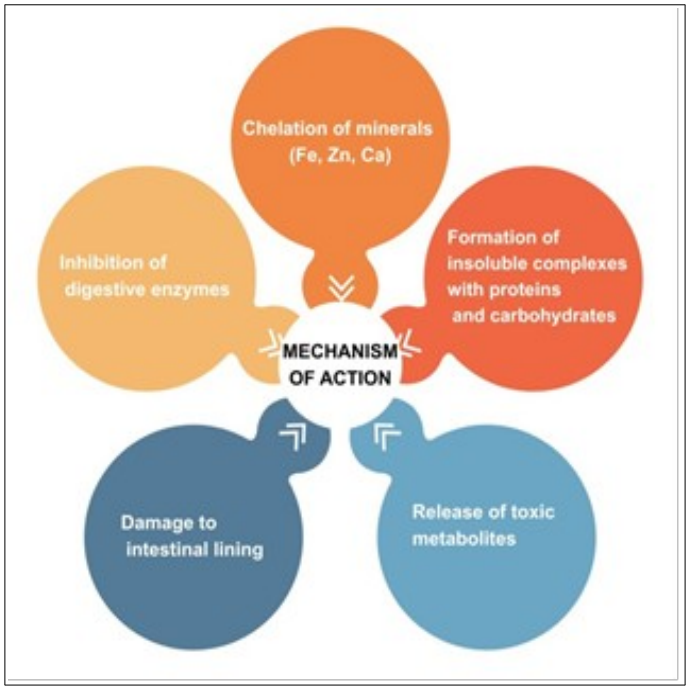


Fig. 3. Different mechanisms of action of antinutritional factors.

The goitrogenic compounds, particularly glucosinolates, are mainly found in cruciferous vegetables like cabbage, cauliflower and broccoli and have a series of compounds belonging to the family of the goitrogens (27). Most of them are secondary plant metabolites comprising a core structure with a β-D-thioglucose group linked to a sulfonated aldoxime moiety and a variable chain derived from amino acids (Fig. 4) (28). The derived products, such as thiocyanates, isothiocyanates and epithionitrile, are produced from glucosinolates by the enzyme myrosinase during the process of cutting and mastication (29). Consumption of glucosinolates and their derived products may alter thyroid function and an increased risk of various thyroid diseases (20). These compounds reduce the release of iodine from the thyroid gland by acting as a competitive inhibitor of the sodium/iodide symporter of follicular thyroid cells (30, 31).

Protease inhibitors are commonly found in cereals and legumes (13). These inhibitors bind to protein-digesting enzymes, blocking protein hydrolysis and thereby affecting protein utilisation. Persistent inhibition of protein-digesting enzymes reduces amino acid availability and may induce pancreatic hypertrophy (24). Saponins, at high concentrations, interact with membrane sterols and enhance intestinal permeability (14).

Effects of antinutritional factors on human and animal nutrition

In humans, kidney stones are caused by oxalates, which bind calcium, creating calcium (Ca) deficiency and urinary calculi in animals (18). Phytates reduce iron (Fe), zinc (Zn) and Ca absorption in humans and mineral deficiencies and stunted growth in pigs and poultry (18, 32). Tannins reduce Fe absorption and protein digestibility in humans and decrease feed intake and growth rate in animals (32, 33). The influence of major ANFs on human and animal nutrition and health is listed in Table 2 and their role in the growth and development of humans and animals is illustrated in Fig. 5.

Table 2. Effects of antinutritional factors on human and animal nutrition

Sl. No.	Antinutritional factors	Effect in humans	Effect in animals	Citation
1.	Phytates	Reduce absorption of Fe, Zn, Ca → mineral deficiency	Poor growth and mineral deficiency in poultry and pigs	(18, 32)
2.	Tannins	Decrease protein digestibility and iron absorption	Reduced feed intake and growth rate	(32, 33)
3.	Oxalates	Kidney stone formation (binds calcium)	Calcium deficiency, urinary calculi	(18)
4.	Lectins	Damage intestinal lining, cause diarrhea	Gut irritation and poor nutrient absorption	(32)
5.	Protease inhibitors	Reduce protein digestion	Pancreatic enlargement and poor feed efficiency	(32, 33)
6.	Amylase inhibitors	Reduce starch digestion	Lower energy utilisation	(17, 32)
7.	Saponins	Bitter taste, may cause hemolysis in excess	Reduced palatability and growth	(17, 33)

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

8.	Cyanogenic glycosides	Cyanide poisoning (in high intake)	Toxicity, respiratory distress	(18)
9.	Glucosinolates	Thyroid enlargement (goiter)	Reduced thyroid function and growth	(31, 33)
10.	Gossypol	Toxic in high levels	Reduced fertility and growth depression	(33)

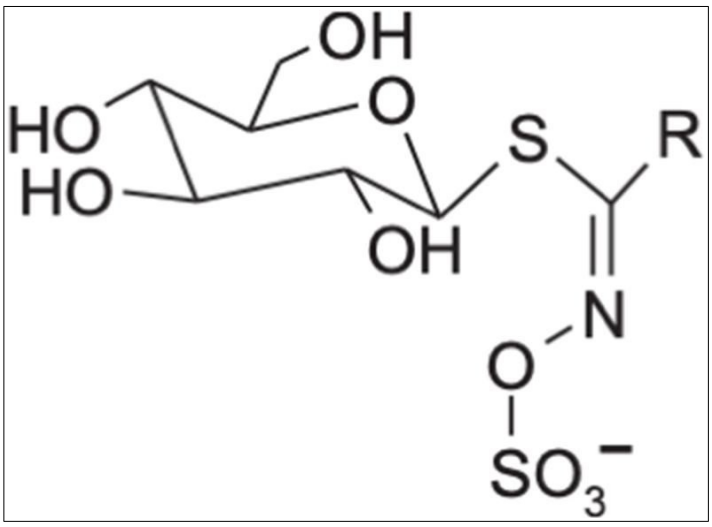


Fig. 4. General structure of glucosinolates. R denotes the variable side chain from amino acids. Source: Adapted from Reference (28).

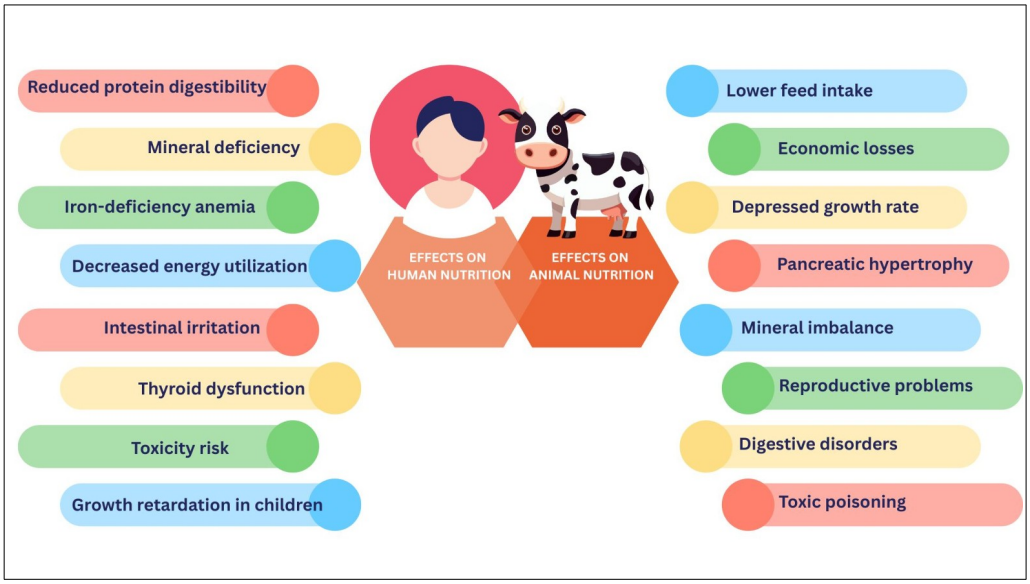


Fig. 5. Role of antinutritional factors on growth and development of human and animals.

Beneficial role of antinutritional factors

Recent research studies on wheat using traditional and molecular breeding and genetic engineering tools have revealed the dual nature of ANFs. Traditionally recognised for their capacity to interfere with nutrient bioavailability and utilisation, ANFs are increasingly acknowledged for their potential beneficial roles in human health (Fig. 6). At controlled levels, lectins exhibit immunomodulatory and anti-cancer properties by detoxifying harmful substances, preventing the uncontrolled multiplication of cancerous cells and activating apoptosis (34). Despite the inhibitory properties of phytic acid, it also acts as a potent antioxidant by scavenging free radicals, thereby reducing oxidative stress following the microbial fermentation process (35). Intake of phytic acid-rich foods, such as beans, has been associated with a reduced risk of cardiovascular diseases (36). Additionally, the heat-stable tannins released during the fermentation process of food materials have strong antiviral, antibacterial, anti-inflammatory and antioxidant properties (37). By interacting with bile acids and cholesterol in the gut and encouraging their evacuation, saponins reduce plasma cholesterol levels (38). Therefore, it is essential to develop strategies for lowering ANF levels in order to maximise their potential positive benefits through appropriate evaluation procedures.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

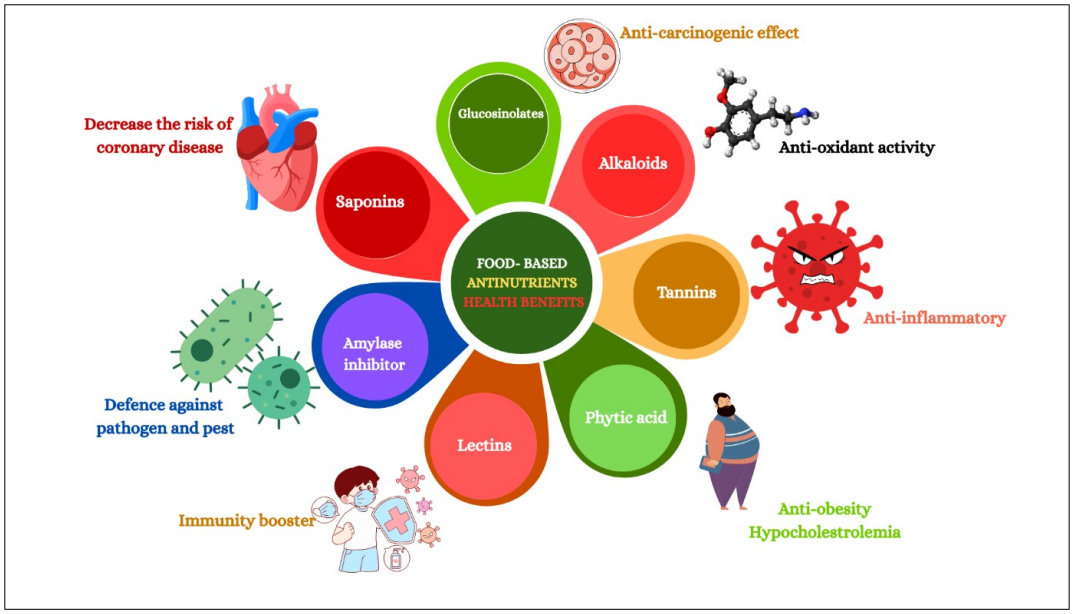


Fig. 6. Beneficial effects of antinutritional factors.

Reduction of antinutritional factors (ANFs)

Food processing approach

Excessive processing may result in the loss of essential nutrients; therefore, complete removal of antinutritional factors is not desirable. A careful balance is required to maintain the beneficial effects of antinutrients while reducing their detrimental impacts (39, 40). Several processing methods, including thermal treatment, extrusion, fermentation and enzymatic modification, are effective in reducing ANF content in foods, thereby enhancing nutrient bioavailability (41). Thermal processing is particularly useful for reducing heat-labile ANFs in legumes and cereals. Heat-sensitive compounds are denatured during treatments such as boiling, roasting, autoclaving and pressure cooking (42). Levels of antinutritional factors like saponins, tannins, cyanides, oxalates, phytates and phenolic compounds can be considerably reduced through boiling and roasting (43). The combined application of high temperature, pressure and mechanical shear has also proved effective in reducing ANFs while improving protein digestibility in plant protein blends (44).

Fermentation, a biotechnological process, is a powerful strategy for reducing ANFs through the activation of endogenous enzymes and microbial enzyme production (45). Microbial degradation activates enzymes such as phytase, which degrades phytic acid, thereby improving nutrient availability (25). Novel non-thermal processing (NTP) methods are increasingly explored as alternatives to conventional heat treatments, preserving heat-sensitive nutrients while reducing ANFs (46). Emerging techniques, including microwave heating, high-pressure processing, ultrasound extrusion and dielectric heating, are effective in reducing heat-labile inhibitors (47). Ozonation and cold plasma treatments reduce ANFs while retaining sensory and nutritional quality (48). Fluidised bed drying has been recognised to reduce certain enzyme inhibitors, although it is less effective against thermostable ANFs, such as phytates (49).

Agronomic, genetic and biotechnological approaches

Agronomic and genetic strategies serve as interconnected and complementary pathways for crop improvement and agricultural sustainability, particularly in the context of rising global food demand and increasing environmental constraints (50). The integration of these approaches is widely adopted to develop cropping systems that are climate-resilient, high-yielding and efficient in resource utilisation (51). Agronomic strategies primarily focus on field-level management practices that enhance crop productivity, optimise input use and strengthen resilience to environmental stress (52). These practices include optimising plant population and spacing, implementing precise irrigation management, adopting integrated nutrient management techniques, ensuring effective weed and pest control and selecting suitable tillage methods (53). Enhancing nitrogen use efficiency through the combined application of agronomic practices and genetic improvements is essential for sustainable production systems and for reducing environmental issues such as nutrient leaching and greenhouse gas emissions (54).

Targeted agronomic interventions can further strengthen plant tolerance to abiotic stresses such as drought (55), salinity, waterlogging (hypoxia) and lodging (56). Agronomic biofortification, involving the application of micronutrient fertilisers, has emerged as an effective strategy to enhance micronutrient levels in edible plant parts and combat hidden hunger, particularly in sub-Saharan Africa (57). Nitrogen management was associated with phytate levels in grains, as evident in wheat with higher mass concentrations of phytate-P and a higher phytate-P/P ratio with no nitrogen application, while N fertilisation increased yield and micronutrient bioavailability without a proportional rise in phytate (58). Overall, contemporary agronomy adopts a system-based

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

and holistic framework to address soil degradation, biodiversity loss and environmental pollution resulting from intensive agricultural practices (59).

Crop genetic improvement has been practiced since the beginning of agriculture through the selection and hybridisation of desirable traits present in landraces and wild relatives (60). Conventional breeding methods, combined with technological innovations and improved agronomic management, have played a significant role in achieving the substantial yield gains observed during the green revolution (61). Marker-assisted selection (MAS) employs molecular markers linked to desirable genes to enhance selection efficiency and reduce the time required for breeding compared with conventional phenotypic methods (62). Speed breeding techniques in wheat reduced the time required for developing heat-tolerant wheat varieties in China (63). Genomic selection (GS) utilises genome-wide marker information to estimate breeding values, providing greater accuracy for improving complex traits governed by multiple genes than MAS (64).

Advanced genome editing tools, such as CRISPR-Cas9, TALENs and zinc finger nucleases (ZFNs), allow precise and targeted modifications to plant genomes, enabling rapid improvement of specific traits in elite cultivars (65) such as the production of maize mutants by disrupting the IPK1 locus, which not only conferred herbicide tolerance but also altered the inositol phosphate profile in developing seeds (66). Omics-based technologies, including genomics, transcriptomics, proteomics and metabolomics, are increasingly utilised to clarify gene functions and regulatory mechanisms associated with yield and stress tolerance traits (67). Understanding and decoding gene regulatory networks offer significant potential for improving crop resilience and sustaining productivity under changing climatic scenarios (68).

Future options for the management of antinutritional factors

The future management of ANFs requires a shift from indiscriminate elimination toward precise modulation strategies that balance nutritional enhancement with the preservation of plant defense mechanisms and functional benefits. Evidence indicates that many ANFs, including phytates, tannins, lectins, protease inhibitors and saponins, contribute to plant stress resistance and seed vigour; therefore, excessive genetic reduction may negatively affect crop yield, resilience and processing traits (69). The Irish potato famine serves as a historical illustration of this vulnerability, since *Phytophthora infestans* caused catastrophic crop loss due to a high reliance on a genetically homogeneous potato variety (70). Simultaneously, ANFs exhibit documented bioactive properties, including anticancer, cardiometabolic, antioxidant, anti-inflammatory and antimicrobial effects, along with technological applications in food preservation, colouration and functional ingredient development (71). Hence, complete removal is neither nutritionally nor biologically desirable.

Crop- and trait-specific strategies are essential because legumes, cereals, oilseeds and crops such as soybean, common bean, faba bean and wheat differ substantially in their ANF profiles, requiring tailored breeding and processing interventions. Moreover, the pleiotropic consequences of low-ANF mutants on stress tolerance, end-use quality and technological performance remain insufficiently understood, highlighting the need for deeper functional characterisation (72). Processing interventions remain central to ANF management. Traditional methods such as soaking, fermentation, germination, autoclaving and thermal treatments, as well as emerging non-thermal technologies including ultrasound, cold plasma, high-pressure processing, pulsed electric fields, irradiation, extrusion and solid-state fermentation, can effectively reduce many ANFs (73).

From a human nutrition perspective, ANFs demonstrate a dualistic nature. Compounds such as phytates, oxalates, tannins, saponins, lectins, protease and amylase inhibitors and cyanogenic glycosides can impair protein digestibility, reduce amino acid availability, chelate essential minerals and contribute to micronutrient deficiencies or growth impairment when consumed in high amounts or in inadequately processed foods. Diets heavily dependent on unprocessed cereals and legumes may therefore exhibit reduced protein quality and digestibility (74). Conversely, moderate intake levels are associated with beneficial physiological effects, including improved glycemic control, lipid profile regulation, antioxidant and anti-inflammatory activity and potential reductions in cardiometabolic disease and certain cancers. Emerging evidence further suggests possible anti-obesity, immunomodulatory and anti-aging properties mediated through the modulation of oxidative stress, inflammation and autophagy pathways (3, 34).

This review has envisaged interest in ANFs as potential functional food components and plant-derived therapeutic leads. Processing technologies, both conventional and advanced, can substantially decrease ANF levels while attempting to maintain beneficial bioactivity (75). Techniques like microbial fermentation, along with the targeted application of probiotics and postbiotics, show considerable promise for selective biodegradation of ANFs (76). The heat-stable compounds such as certain phytates and tannins remain difficult to reduce without compromising nutrient retention and comprehensive *in vivo* data, regulatory frameworks and clearly defined tolerance limits for human and ruminant health need to be studied in detail (77).

Conclusion

Plants contain antinutritional factors (ANFs) at different concentrations, which have both harmful and beneficial effects. Antinutritional factors are produced by plants as defence mechanisms and include compounds that can alter nutrient digestion and absorption. High levels of ANFs can lead to negative health outcomes, as reported with phytic acid in cereals and legumes, which binds with

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

minerals, reducing their bioavailability, particularly that of iron (Fe). Lectins, which are found in legumes and cereals, impair nutrient absorption by binding to intestinal cells. Tannins, found in various foods, decrease protein digestibility and bind to essential nutrients, making them unavailable. Some root crops, like cassava, produce cyanogenic glycosides, which release toxic hydrogen cyanide when disrupted, affecting cellular respiration. Also, the goitrogenic compounds in cruciferous vegetables can cause hypothyroidism, while protease inhibitors in cereals affect protein utilisation by cells and saponins increase intestinal permeability at high concentrations. However, moderate concentrations of ANFs may offer health benefits, such as antioxidants and anti-inflammatory properties.

The impact of ANFs varies based on factors like age, species and food processing. Hence, diverse, properly processed plant-based diets can minimise nutritional risks while harnessing potential protective effects, whereas monotonous, poorly processed staple-based diets may heighten deficiency and toxicity concerns. Conventional and advanced breeding techniques can be employed to maintain desirable characteristics in crop varieties. These techniques can be coupled with precise agronomic approaches such as biofortification with nutrients to manage the levels of ANFs and reduce their adverse effects while preserving health-promoting qualities to enhance nutritional security.

Acknowledgements

The authors acknowledge the Tamil Nadu Agricultural University for the support rendered for conducting the review.

Authors' contributions

MM collected the materials and prepared the draft manuscript. RN conceived the research review, mentored the review process, collected the literature and corrected and edited the manuscript. GPK, PM, RP, RK and RA assisted in editing the article. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used CANVA and QuillBot solely for language editing and grammar improvement. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

References

1. Cavalcandi RN, Foster-Carneiro T, Gomes MTMS, Rostagno MA, Prado JM, Meireles MAA. Uses and applications of extracts from natural sources. In: Prado JM, Rostagno MA, editors. Natural product extraction: principles and applications. 2nd ed. London: Royal Society of Chemistry; 2022. p. 1–57. https://doi.org/10.1039/9781839165894-00001
2. Ali A, Devarajan S, Manickavasagan A, Ata A. Antinutritional factors and biological constraints in the utilization of plant protein foods. In: Manickavasagan A, Ali A, editors. Plant protein foods. Cham: Springer Nature; 2022. p. 407–38. https://doi.org/10.1007/978-3-030-91206-2_14
3. Salim R, Nehvi I, Mir R, Tyagi A, Ali S, Bhat O. A review on anti-nutritional factors: unraveling the natural gateways to human health. Front Nutr. 2023;10:1215873. https://doi.org/10.3389/fnut.2023.1215873
4. Samtiya M, Aluko RE, Dhewa T. Plant food anti-nutritional factors and their reduction strategies: an overview. Food Prod Process Nutr. 2020;2:1–14. https://doi.org/10.1186/s43014-020-0020-5
5. Popova A, Mihaylova D. Antinutrients in plant-based foods: a review. Open Biotechnol J. 2019;13:68–76. https://doi.org/10.2174/1874070701913010068
6. Gemede HF, Ratta N. Antinutritional factors in plant foods: potential health benefits and adverse effects. Int J Nutr Food Sci.2014;3(4):284–9. https://doi.org/10.11648/j.ijnfs.20140304.18
7. Ahmad Z, Ahmad A, Subtain M, Naeem M. Anti-nutritional characterization of plant foods: health consequences and reduction strategies. J Food Meas Charact. 2025;19(9):6264–83. https://doi.org/10.1007/s11694-025-03432-1
8. Pihlanto A, Mattila P, Mäkinen S, Pajari AM. Bioactivities of alternative protein sources and their potential health benefits. Food Funct. 2017;8:3443–58. https://doi.org/10.1039/C7FO00302A
9. Thakur P, Kumar P. Anti-nutritional factors, their adverse effects and the need for adequate processing to reduce them in food. Agric Food e-Newsl. 2017;4:56. https://doi.org/10.5958/2454-8634.2017.00013.4
10. Arsov A, Tsigoriyna L, Batovska D, Armenova N, Mu W, Zhang W, et al. Bacterial degradation of antinutrients in foods: genomic insights. Foods. 2024;13(15):2408. https://doi.org/10.3390/foods13152408
11. Ohanenye IC, Ekezie FGC, Sarteshnizi RA, Boachie RT, Emenike CU, Sun X, et al. Legume seed protein digestibility as influenced by traditional and emerging physical processing technologies. Foods. 2022;11(15):2299. https://doi.org/10.3390/foods11152299
12. Singh P, Pandey VK, Sultan Z, Singh R, Dar AH. Classification, benefits and applications of various anti-nutritional factors present in edible crops. J Agric Food Res. 2023;14:100902. https://doi.org/10.1016/j.jafr.2023.100902

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

13. Ram S, Narwal S, Gupta OP, Pandey V, Singh GP. Anti-nutritional factors and bioavailability: approaches, challenges and opportunities. In: Shewry MS, Halford NG, editors. Wheat and barley grain biofortification. Kidlington, United Kingdom: Elsevier; 2020. p. 101–28. https://doi.org/10.1016/B978-0-12-818444-8.00004-3

14. Akande KE, Doma UD, Agu HO, Adamu HM. Major antinutrients found in plant protein sources: their effect on nutrition. Pak J Nutr. 2010;9(8):827–32. https://doi.org/10.3923/pjn.2010.827.832

15. Tuncel N, Kaya H, Andaç A, Korkmaz F, Tuncel N. A comprehensive review of antinutrients in plant-based foods and their key ingredients. Nutr Bull. 2025;50:171–205. https://doi.org/10.1111/nbu.12732

16. Sułek A, Cacak-Pietrzak G, Studnicki M, Grabiński J, Nieróbca A, Wyzińska M, et al. Influence of nitrogen fertilisation level and weather conditions on yield and quantitative profile of anti-nutritional compounds in grain of selected rye cultivars. Agriculture. 2024;14(3):418. https://doi.org/10.3390/agriculture14030418

17. Liener IE. Implications of antinutritional components in soybean foods. Crit Rev Food Sci Nutr. 1994;34(1):31–67. https://doi.org/10.1080/10408399409527649

18. Kumar V, Sinha AK, Makkar HPS, Becker K. Dietary roles of phytate and phytase in human nutrition: a review. Food Chem.2010;120(4):945–59. https://doi.org/10.1016/j.foodchem.2009.11.052

19. Duodu KG, Taylor JRN, Belton PS, Hamaker BR. Factors affecting sorghum protein digestibility. J Cereal Sci. 2003;38(2):117–31. https://doi.org/10.1016/S0733-5210(03)00016-X

20. Tripathi MK, Mishra AS. Glucosinolates in animal nutrition: a review. Anim Feed Sci Technol. 2007;132(1):1–27. https://doi.org/10.1016/j.anifeedsci.2006.03.003

21. Cardoso AP, Mirione E, Ernesto M, Massaza F, Cliff J, Haque MR, et al. Processing of cassava roots to remove cyanogens. Food Nutr Bull. 2005;26(3):245–50. https://doi.org/10.1016/j.jfca.2004.04.002

22. Gupta S, Lakshmi AJ, Manjunath MN, Prakash J. Analysis of nutrient and antinutrient content of underutilized green leafy vegetables. Plant Foods Hum Nutr. 2005;60(4):183–9. https://doi.org/10.1016/j.lwt.2004.06.012

23. Tyagi K, Kohli V, Sikka K, Kumari M. Advanced insights into the role of food processing, fortification and antinutritional factors on iron absorption. J Neonatal Surg. 2025;14(5S):288–99. https://doi.org/10.52783/jns.v14.2040

24. Lallès JP, Jansman AJM. Recent progress in the understanding of the mode of action and effects of antinutritional factors from legume seeds in non-ruminant farm animals. In: EAAP Publication. Vol. 93. Wageningen: Wageningen Pers; 1998. https://doi.org/10.1163/9789004683921_031

25. Jeyakumar E, Lawrence R. Microbial fermentation for reduction of antinutritional factors. In: Pandey A, Larroche C, Soccol CR, editors. Current developments in biotechnology and bioengineering. Elsevier; 2022. p. 239–60. https://doi.org/10.1016/B978-0-12-823506-5.00012-6

26. Gänzle MG. Food fermentations for improved digestibility of plant foods-an essential *ex-situ* digestion step in agricultural societies? Curr Opin Food Sci. 2020;32:124–32. https://doi.org/10.1016/j.cofs.2020.04.002

27. Felker P, Bunch R, Leung AM. Concentrations of thiocyanate and goitrin in human plasma, their precursor concentrations in brassica vegetables and associated potential risk for hypothyroidism. Nutr Rev. 2017;74(4):248–58. https://doi.org/10.1093/nutrit/nuv110

28. Redovniković IR, Glivetić T, Delonga K, Vorkapić-Furač J. Glucosinolates and their potential role in plant. Period Biol. 2008;110:297–309.

29. Prieto MA, López CJ, Simal-Gandara J. Glucosinolates: molecular structure, breakdown, genetic, bioavailability, properties and healthy and adverse effects. In: Ferreira ICFR, Barros L, editors. Functional food ingredients from plants. Vol. 90. Elsevier; 2019. p. 305–50. https://doi.org/10.1016/bs.afnr.2019.02.008

30. Di Bernardo J, Iosco C, Rhoden KJ. Intracellular anion fluorescence assay for sodium/iodide symporter substrates. Anal Biochem. 2011;415(1):32–8. https://doi.org/10.1016/j.ab.2011.04.017

31. Hanschen FS, Lamy E, Schreiner M, Rohn S. Reactivity and stability of glucosinolates and their breakdown products in foods. Angew Chem Int Ed. 2014;53:11430–50. https://doi.org/10.1002/anie.201402639

32. Gilani GS, Cockell KA, Sepehr E. Effects of antinutritional factors on protein digestibility and amino acid availability in foods. J AOAC Int. 2005;88(3):967–87. https://doi.org/10.1093/jaoac/88.3.967

33. Francis G, Makkar HPS, Becker K. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture. 2001;199(3–4):197–227. https://doi.org/10.1016/S0044-8486(01)00526-9

34. Karabulut G, Günal-Köroğlu D, Yılmaz H, Erskine E, Capanoglu E. Contradictory dual role of antinutrients in nutrient inhibition and anti-aging: a comprehensive review on health benefits, processing techniques and dietary strategies. Ageing Res Rev. 2026;113:102929. https://doi.org/10.1016/j.arr.2025.102929

35. Chen W, Xu D. Phytic acid and its interactions in food components, health benefits and applications: a comprehensive review. Trends Food Sci Technol. 2023;141:104201. https://doi.org/10.1016/j.tifs.2023.104201

36. Vieira NM, Peghinelli VV, Monte MG, Costa NA, Pereira AG, Seki MM, et al. Beans consumption can contribute to the prevention of cardiovascular disease. Clin Nutr ESPEN. 2023;54:73–80. https://doi.org/10.1016/j.clnesp.2023.01.007

37. Nath H, Samtiya M, Dhewa T. Beneficial attributes and adverse effects of major plant-based foods' anti-nutrients on health: a review. Hum Nutr Metab. 2022;28:200147. https://doi.org/10.1016/j.hnm.2022.200147

38. Thompson LU. Potential health benefits and problems associated with antinutrients in foods. Food Res Int. 1993;26(2):131–49. https://doi.org/10.1016/0963-9969(93)90069-U

39. Nkhata SG, Ayua E, Kamau EH, Shingiro JB. Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. Food Sci Nutr. 2018;6(8):2446–58. https://doi.org/10.1002/fsn3.846

40. Jithender B, Upendar NK, Rathod PJ. Nutritional and anti-nutritional factors present in oil seeds: an overview. Int J Chem Stud. 2019;7(6):1159–65.

41. Dewan MF, Shams S, Haque MA. Impact of processing on the bioactive compounds and antinutritional factors of lentil (*Lens culinaris* L.)—a review. Legume Sci. 2024;6(3):e253. https://doi.org/10.1002/leg3.253

42. Van der Poel AFB. Effect of processing on antinutritional factors and protein nutritional value of dry beans (*Phaseolus*

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

vulgaris L.): a review. Anim Feed Sci Technol. 1990;29(3–4):179–208. https://doi.org/10.1016/0377-8401(90)90027-6

43. Haruna M, Bichi A, Ibrahim S, Sambo F. Effects of different heat processing methods on the antinutritional factors (ANFs) level of *P. reticulatum* seed meal. Bayero J Pure Appl Sci. 2016;8(2):233–7. https://doi.org/10.4314/bajopas.v8i2.38

44. Duque-Estrada P, Hardiman K, Bøgebjerg Dam A, Dodge N, Aaslyng MD, Petersen IL. Protein blends and extrusion processing to improve the nutritional quality of plant proteins. Food Funct. 2023;14(16):7361–74. https://doi.org/10.1039/D2FO03912E

45. Tee AJ, Lim YS, Brameld JM, Massawe F, Parr T, Salter AM. Fermentation technology enhances the nutritional quality of underutilized Bambara groundnut-a review. Food Biotechnol. 2023;37(2):106–35. https://doi.org/10.1080/08905436.2023.2201307

46. Sanaei Nasab S, Tahmouzi S, Feizollahi E, Mollakhalili-Meybodi N. Impacts of novel non-thermal processing (NTP) on anti-nutritional compounds of food grains and seeds. Food Control.2024;162:110469. https://doi.org/10.1016/j.foodcont.2024.110469

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

48. Faizal F, Ahmad N, Yaacob J, Lim SJ, Rahim MA. Food processing to reduce antinutrients in plant-based foods. Int Food Res J. 2023;30(1):1–12. https://doi.org/10.47836/ifrj.30.1.02

49. Cheng S, Langrish T. A review of the treatments to reduce anti-nutritional factors and fluidized bed drying of pulses. Foods.2025;14(4):681. https://doi.org/10.3390/foods14040681

50. Mohanty LK, Singh NK, Raj P, Prakash A, Tiwari AK, Singh V, et al. Nurturing crops, enhancing soil health and sustaining agricultural prosperity worldwide through agronomy. J Exp Agric Int. 2024;46(2):46–67. https://doi.org/10.9734/jeai/2024/v46i22308

51. Weih M, Didon UME, Rönnberg-Wästljung AC, Björkman C. Integrated agricultural research and crop breeding: allelopathic weed control in cereals and long-term productivity in perennial biomass crops. Agric Syst. 2008;97(3):99–107. https://doi.org/10.1016/j.agsy.2008.02.009

52. Anbarasan S, Ramesh S. Innovations in agronomy for sustainable crop production. Plant Sci Arch. 2022;7(3):1–4. https://doi.org/10.51470/PSA.2022.7.3.01

53. Sharma OP, Kushwah N, Singh D, Chauhan APS, Jain M. Agronomic approaches to mitigation of the impact of climate change on plants. Plant Sci Arch. 2023;8(2):4–6. https://doi.org/10.51470/PSA.2023.8.2.04

54. Ali A, Jabeen N, Farruhbek R, Chachar Z, Laghari AA, Chachar S, et al. Enhancing nitrogen use efficiency in agriculture by integrating agronomic practices and genetic advances. Front Plant Sci. 2025;16:1543714. https://doi.org/10.3389/fpls.2025.1543714

55. Alhaithloul HA, Soliman MH, Ameta KL, El-Esawi MA, Elkelish A. Changes in ecophysiology, osmolytes and secondary metabolites of the medicinal plants of *Mentha piperita* and *Catharanthus roseus* subjected to drought and heat stress. Biomolecules. 2019;10(1):43. https://doi.org/10.3390/biom10010043

56. Mariani L, Ferrante A. Agronomic management for enhancing plant tolerance to abiotic stresses-drought, salinity, hypoxia and lodging. Horticulturae. 2017;3(4):52. https://doi.org/10.3390/horticulturae3040052

57. de Valença A, Bake A, Brouwer I, Giller K. Agronomic biofortification of crops to fight hidden hunger in sub-Saharan Africa. Glob Food Sec. 2017;12:8–14. https://doi.org/10.1016/j.gfs.2016.12.001

58. Xia H, Li X, Qiao Y, Xue Y, Yan W, Ma L, et al. Dissecting the relationship between yield and mineral nutriome of wheat grains in double cropping as affected by preceding crops and nitrogen application. Field Crops Res. 2023;293:108845. https://doi.org/10.1016/j.fcr.2023.108845

59. Al-Shammary AAG, Al-Shihmani LSS, Fernández-Gálvez J, Caballero-Calvo A. Optimizing sustainable agriculture: a comprehensive review of agronomic practices and their impacts on soil attributes. J Environ Manage. 2024;364:121487. https://doi.org/10.1016/j.jenvman.2024.121487

60. Babar M, Nawaz M, Shahani A, Khalid M, Latif A, Kanwal K, et al. Genomic-assisted crop breeding approaches for designing future crops to combat food production challenges. Biol Clin Sci Res J. 2022;2022(1):143. https://doi.org/10.54112/bcsrj.v2022i1.143

61. Thudi M, Palakurthi R, Schnable JC, Chitikineni A, Dreisigacker S, Mace E, et al. Genomic resources in plant breeding for sustainable agriculture. J Plant Physiol. 2021;257:153351. https://doi.org/10.1016/j.jplph.2020.153351

62. Ahmar S, Gill RA, Jung KH, Faheem A, Qasim MU, Mubeen M, et al. Conventional and molecular techniques from simple breeding to speed breeding in crop plants: recent advances and future outlook. Int J Mol Sci. 2020;21(7):2590. https://doi.org/10.3390/ijms21072590

63. Zheng Z, Wang HB, Chen GD, Yan GJ, Liu CJ. A procedure allowing up to eight generations of wheat and nine generations of barley per annum. Euphytica. 2013;191(2):311–6. https://doi.org/10.1007/s10681-013-0909-z

64. He T, Li C. Harness the power of genomic selection and the potential of germplasm in crop breeding for global food security in the era of rapid climate change. Crop J. 2020;8(5):688–700. https://doi.org/10.1016/j.cj.2020.04.005

65. Khan AA, Iqbal B, Jalal A, Khan KA, Al-Andal A, Khan I, et al. Advanced molecular approaches for improving crop yield and quality: a review. J Plant Growth Regul. 2024;43(7):2091–103. https://doi.org/10.1007/s00344-024-11253-7

66. Shukla VK, Doyon Y, Miller JC, DeKelver RC, Moehle EA, Worden SE, et al. Precise genome modification in the crop species *Zea mays* using zinc-finger nucleases. Nature. 2009;459(7245):437–41. https://doi.org/10.1038/nature07992

67. Kumar S, Singh A, Bist CMS, Sharma M. Advancements in genetic techniques and functional genomics for enhancing crop traits and agricultural sustainability. Brief Funct Genomics.2024;23(5):607–23. https://doi.org/10.1093/bfgp/elae017

68. Leong R, He X, Beijen BS, Sakai T, Goncalves J, Ding P. Unlocking gene regulatory networks for crop resilience and sustainable agriculture. Nat Biotechnol. 2025;43(8):1254–65. https://doi.org/10.1038/s41587-025-02727-4

69. Duraiswamy ANKS, Selvaraj SJL, Selvaraj RKI, Sheriff S, Thinakaran J, Rathinamoorthy SPR. Genetic manipulation of anti-nutritional factors in major crops for a sustainable diet in future. Front Plant Sci. 2023;13:1070398. https://doi.org/10.3389/fpls.2022.1070398

70. Yoshida K, Schuenemann VJ, Cano LM, Pais M, Mishra B, Sharma R, et al. The rise and fall of the *Phytophthora*

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16563

infestans lineage that triggered the Irish potato famine. Elife. 2013;2:e00731. https://doi.org/10.7554/eLife.00731

71. Negi R, Jan T, Kaur T, Khan S, Yadav N, Rai A, et al. Bioactive compounds as plant-based functional foods for human health: current scenario and future challenges. J Appl Biol Biotechnol. 2025;13(1):1–23. https://doi.org/10.7324/JABB.2024.180889

72. Mahalakshmi R, Indu C, Savitha B, Subramanian A, Sudha M, Gurusamy K. Sustainable strategies to combat anti-nutrition in legumes: implications for global food security. Plant Sci Today. 2025;12(2). https://doi.org/10.14719/pst.5485

73. Álvarez A, Rodríguez A, Chaparro S, Borrás L, Rache L, Brijaldo M, et al. Solid-state fermentation as a biotechnological tool to reduce antinutrients and increase nutritional content in legumes and cereals for animal feed. Fermentation.2025;11(7):359. https://doi.org/10.3390/fermentation11070359

74. Gilani GS, Xiao CW, Cockell KA. Impact of antinutritional factors in food proteins on the digestibility of protein and the bioavailability of amino acids and on protein quality. Br J Nutr. 2012;108(S2):S315–32. https://doi.org/10.1017/S0007114512002371

75. Kong X, Li Y, Liu X. A review of thermosensitive antinutritional factors in plant-based foods. J Food Biochem. 2022;46(8):e14199. https://doi.org/10.1111/jfbc.14199

76. Khani N, Shakeri A, Ashkezary M, Aghapour B, Soleimani R, Hosseinzadeh N, et al. Potential of postbiotics in the biodegradation of antinutrients in foods. Probiotics Antimicrob Proteins. 2025;18:2942–53. https://doi.org/10.1007/s12602-025-10649-5

77. Kumar R. Anti-nutritional factors, the potential risks of toxicity and methods to alleviate them. In: Legume trees and other fodder trees as protein sources for livestock. Vol. 102. FAO Food and Agriculture Organization of the United Nations. Animal Production and Health Paper; 1992. p. 145–60.

Additional information

Peer review: Publisher thanks the Sectional Editor and anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information: Available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy.

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting.

Copyright: © The Author(s). This is an open-access article distributed under the Creative Commons Attribution License CC BY 4.0.

Publisher information: Plant Science Today is published by Horizon e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.

https://doi.org/10.14719/pst.16563