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Scientific approaches for alleviating anti-nutritional compounds in vegetables and their impediments

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Abstract
Vegetables are one of the important sources of micronutrients and they are a part of a healthy diet. These are considered an important food source because contain ample amounts of minerals and vitamins that promote good health. They comprise 20% of an Indian meal and help in the proper growth and maintenance of the body. The nutritional and anti-nutritional content in different types of edible leafy vegetables differs from one plant species to another. Anti-nutritional factors are chemical substances found in plant tissues that hinder the body's absorption of nutrients. These factors can have varying effects, ranging from mild reactions to severe consequences, including death. Significant anti-nutritional compounds like nitrates, phytates, tannins, oxalates, and Cyanogenic glycosides have been associated with various health-related concerns. However, there are some chemicals and anti-nutritional factors present in them that are known to be biologically active. Some anti-nutritional factors like saponins, oxalates, protease inhibitors, alkaloids, etc., can interfere with several metabolic processes of the body which can deteriorate the overall health of the individual. Therefore, it is necessary to remove these deleterious compounds from vegetables before consumption. Various techniques like boiling, blanching, soaking, steaming, and cooking can be employed in food preparation., and thermal processing have effectively helped to reduce the antinutritional content from them. And it is very essential to promote these methods so that the public could become aware of the measures that should be taken before consuming vegetables.

Keywords: Vegetables, antinutritional factors, secondary metabolites, minerals, soaking, cooking

Introduction

Vegetables are important food source that are loaded with minerals, vitamins and high fibre content. These valuable compounds help to repair and maintain the body and assist several metabolic processes. There are several kinds of vegetables like leafy, tubers, roots, stem, fruit or seed and each group can be utilized in a food in its own way (Sinha and Khare, 2017) [38]. However, these vegetables contain several antinutritional factors that decrease the bioavailability of nutrients and put a negative influence on health (Agbaire and Emoyan, 2018) [1]. However, antinutritional factors (ANF) are the chemical compounds synthesized naturally in plants and exert an opposing effect on availability of nutrients. These compounds are highly biologically active and are also known as ‘secondary metabolites’ (Gemede and Ratta, 2018) [13]. While, there is a wide classification of anti-nutritional factor (ANF) such as saponins, tannins, lectins, protease inhibitors, alkaloids, glycosides, is flavones, phytates, oxalates and many more. Different classes of vegetables contain distinctively wide variety of Antinutrients, for example, vegetables from Alliaceae family like onions, garlic, shallots, are considered to have thiosulfides and flavonoids. Whereas, cruciferous vegetables from Brassicaceae family like cauliflower, cabbage, broccoli, contains high amount of Glucosinolates and those that belong to Cucurbitaceous family like cucumber, pumpkin, bitter gourd, have good number of tocopherols and carotenoids (Natesh *et al.*, 2018) [23]. Undesirable chemical substances referred to as anti-nutrients are abundant in both cultivated and wild plant species (Dagostin *et al.*, 2018) [7]. These substances are also known as "Allelochemicals" (Cheeke *et al.*, 2019) [6], but their quantity and distribution can vary among different plant genera and species. An anti-nutritional factor is not an inherent property of a compound; it depends on how the consuming animal digests it. The severity of its effects largely hinges on dietary habits and the processing method used before consuming the specific plant food. The following section details individual compounds and their impact on the human diet. Some common anti-nutrients found in leafy vegetables include nitrates, oxalates, tannins, phytates, and Cyanogenic glycosides (Cheek and Shull 2019) [6].

Vegetables and anti-nutritional factors

There are many types of antinutritional factors present in vegetables. Some of them are heat labile and cannot be removed easily through processing, which further leads to nutrition related problems and raise the harmful effect on human health. Generally, these factors include saponins, tannins, phytic acid, gossypol, lectins, protease inhibitors, amylase inhibitors, antivitamin factors, metal binding ingredients, goitrogens, etc. (Samtiya *et al*., 2020) [37]. More precisely, the list of antinutritional factors present in vegetables can be classifies as follows, Physiological Disorganizors (lectines, saponins, lathrogens, oxalates, nitrate and nitrite) Cyanogenic glycosides (phaseolunatin, dhurrin, linamarin, lutaustralin) Enzyme Inhibitor (Alkaloids, protease inhibitors, cynogens, G-6-PD, cholinesterase inhibitors, amylose inhibitors) Alterations of Hormonal Actions (goitrogens) Antivitamins. Some of the antinutritional factors present in vegetables are mentioned in (Fig 1).

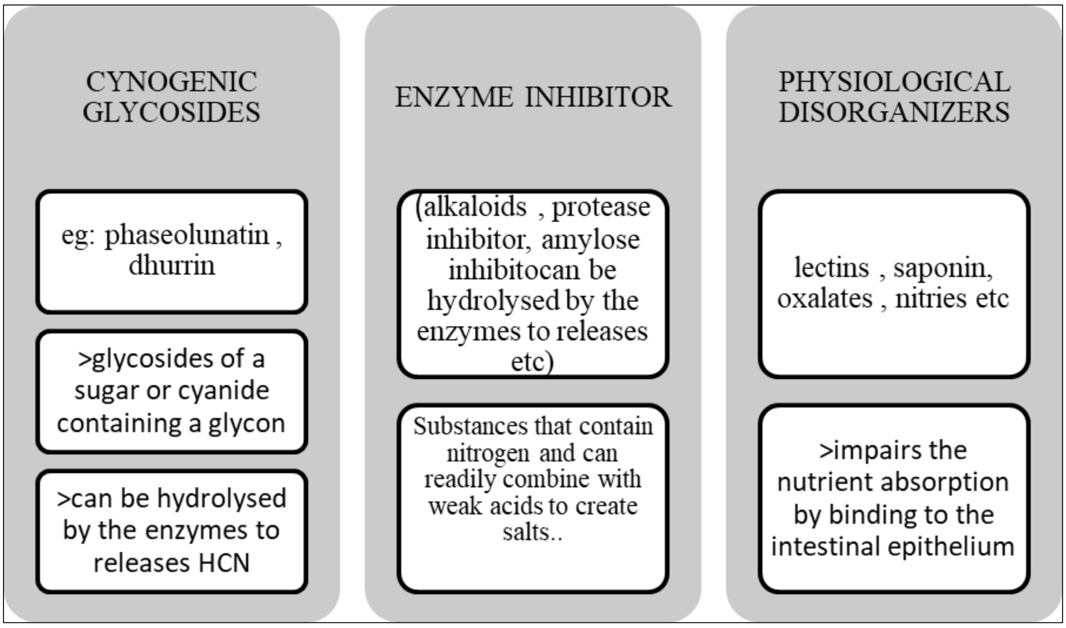

Fig 1: Types of Anti-nutritional factors present in vegetables

Saponins

Saponins are secondary compounds that are generally known as non-volatile, surface- active compounds which are widely distributed in nature, occurring primarily in the plant kingdom. They are found in soybeans, sugar beets, peanuts, spinach, asparagus, broccoli, potatoes, apples, eggplants, alfalfa and ginseng root. Saponins are capable of disrupting red blood cells and producing diarrhoea and vomiting. Although, they reduce the uptake of certain nutrients including glucose and cholesterol at the gut through intraluminal physicochemical interaction. Saponins have also been demonstrated to have anti-spermal effect on human spermatozoa because they can significantly inhibit acrosine activity of human sperms (Sinha and Khare, 2017) [38]. These are also found to reduce the bioavailability of nutrients and decrease enzyme activity as it affects protein digestibility by inhibiting various digestive enzymes such as trypsin and chymotrypsin (Gemede and Ratta, 2019) [63]. Furthermore, when present in high amounts, saponins introduce a bitter taste and astringency to edible plants. The primary reason for the limited utilization of this compound is its bitter taste. Despite its adverse effects, foods rich in saponins play a crucial role in managing plasma cholesterol, preventing peptic ulcers, addressing osteoporosis, and lowering the risk of heart disease (Thakur *et al*., 2019) [40].

Phytates

Phytates or phytic acids occur naturally in the plant kingdom and are generally known as myo-inositol-1,2, 3,4,5,6-hexakis dihydrogen phosphate. The concentration of phytates present in foods at various levels usually range from 0.1 to 6.0% (Gupta *et al*., 2015) [15]. These are primarily present as a salt of the mono and divalent cations K^+, Mg^{2+}, and Ca^{2+} and accumulates in the seeds during the ripening period. They are also regarded as the primary storage form of both phosphate and inositol in plant seeds and grains (Gemede and Ratta, 2019) [63].

According to recent studies, phytic acid has been found to inhibit the activity of enzymes required for protein digestion in the small intestine and stomach. In general, excessive consumption of phytic acids can negatively impact human health, as they affect the bioavailability of minerals. Phytic acid acts as a strong chelator, forming complexes with proteins and minerals, which leads to reduced protein and mineral bioavailability. It also chelates various metal ions, including calcium, magnesium, zinc, copper, iron, and molybdenum, forming insoluble complexes that are not easily absorbed in the gastrointestinal tract. Additionally, phytic acid inhibits the action of gastrointestinal enzymes like tyrosinase, trypsin, pepsin, lipase, and amylase. One of the most significant effects of phytic acid on human nutrition is its reduction of zinc bioavailability, underscoring the importance of reducing its presence in the diet before consumption (Thakur *et al*., 2019) [40]. Plant tannins are a major group of antioxidant polyphenols found in food and beverages that attracts research interest with its multifunctional properties to human health (Popova and Mihaylova, 2019) [51]. Tannin is an astringent, bitter plant polyphenolic compound that either binds or precipitates proteins and various other organic compounds including amino acids and alkaloids. If tannin concentration in the diet becomes too high, microbial enzyme activities including cellulose and intestinal digestion may be depressed. Tannins also form insoluble complexes with proteins and the tannin-protein complexes may be responsible for the antinutritional effects of tannin containing foods (Gemede and Ratta, 2018) [13]. Because of this protein-binding activity, tannins can also interact with enzymes and cause non-specific enzyme inhibition. Condensed tannins have been reported to inhibit lipase, trypsin and α-amylase, which may decrease the absorption of lipids, proteins and carbohydrates, respectively (Lo *et al*, 2018) [20]. Tannins also have the ability to complex with vitamin B. Other adverse nutritional effects of tannins have been reported to include intestinal damage, with iron absorption and the possibility of tannins producing a carcinogenic effect. Toxic effects of tannins can be categorized as: depression of food intake, inhibition of digestive enzymes, increased excretion of endogenous protein, digestive tract malfunctions and toxicity of absorbed tannin metabolites (Thakur *et al*., 2019) [40]. The bitter elements of plants known as alkaloids are widely distributed in nature and frequently have pharmacological characteristics. Alkaloids are frequently basic, nitrogen-containing substances that primarily function as secondary plant metabolites and can form salts with acids (Watkins *et al*., 2019) [41]. At least 40% of plant families have representatives whose roots, seeds, leaves, or bark have yielded alkaloids. Amaryllidaceae, Compositae, Leguminosae, Liliaceae, Papaveraceae, and Solanaceae are some of the families that are exceptionally abundant in alkaloids. Alkaloids Found in Common Foods and Plants The pyrrolizidine alkaloids are one kind of alkaloid that is commonly present in the plant kingdom. Tomatine and solanine are typical examples. Tomatine is an Alkaloid found in tomatoes, whereas solanine is an alkaloid found in minor amounts in potatoes. Due to the way alkaloids affect the nerve system, interrupting or unnaturally enhancing electrochemical transmission, they are regarded as anti-nutrients. For instance, taking significant doses of tropane alkaloids will result in a rapid heartbeat, paralysis, and, in the worst case, death. High doses of tryptamine alkaloids can cause stumbling and even death. Indeed, alkaloids' physiological impacts on people are clearly seen (Fernando and Pathmeswaran, 2018) [12].

A salt formed from oxalic acid is known as an Oxalate: for example, Calcium oxalate, which has been found to be widely distributed in plants. Strong bonds are formed between oxalic acid, and various other minerals, such as Calcium, Magnesium, Sodium, and Potassium. This chemical combination results in the formation of oxalate salts. Some oxalate salts, such as sodium and potassium, are soluble, whereas calcium oxalate salts are basically insoluble. Oxalate is an anti-nutrient typically sequestered in distinct compartments under normal conditions. However, during processing or digestion, it comes into contact with nutrients within the gastrointestinal tract. Upon release, oxalic acid forms bonds with these nutrients, rendering them inaccessible to the body. Regular consumption of foods with excessive oxalic acid content can lead to nutritional deficiencies and severe irritation to the gut lining (Gemede and Ratta, 2019) [13]. Oxalic acid is a product of the oxidative breakdown of carbohydrates and proteins, and it accumulates in plants, particularly during dry conditions. Research on certain tropical leafy vegetables has revealed that dried vegetables contain higher oxalate concentrations than their fresh counterparts (Joshi *et al*., 2020) [16]. Oxalates impact the human body by forming robust chelates with dietary calcium and other minerals, making the complex unavailable for absorption and assimilation. These insoluble calcium oxalate crystals are stored in the kidneys, potentially leading to the development of kidney stones, a serious health concern (Natesh *et al*., 2019) [68].

Cruciferous vegetables such as kale, radishes, cauliflower, broccoli, as well as chard, spinach, parsley, beets, rhubarb, black pepper, chocolate, nuts, berries (blueberries, blackberries), and beans are examples of foods rich in oxalates (Popova and Mihaylova, 2019) [51].

Nitrogen is an essential component for the nutrition and functioning of plants, so plants exert a close metabolic control on the concentration of nitrate and other nitrogen compounds. Leaf crops such as cabbage, lettuce and spinach have fairly large nitrate concentrations whereas storage organs such as potato tubers, carrots, leeks, onions, seeds and pods of pea and bean plants have relatively small concentrations (Sinha and Khare, 2018) [69]. The nitrate content per serving of any vegetable is generally considered non-toxic, but the metabolites and by-products it forms, such as nitrite, nitric oxide, and N-nitrous compounds, are the primary health concerns. Total dietary nitrate intake follows entero-salivary circulation, where it is converted into nitrites by oral bacteria and salivary enzymes (Natesh *et al*., 2019) [68]. Nitrites can react with secondary amines to create carcinogenic N-nitrosamines. There has been reported evidence linking the consumption of nitrate-containing foods to an increased risk of gastric, esophageal, nasopharyngeal, and bladder cancer. Furthermore, nitrites have a higher toxic potential as they can impair the low affinity of hemoglobin for oxygen, leading to methemoglobinemia, which poses a threat to human health (Lo *et al*., 2018) [20]. Cyanogenic glycosides (CN) are compounds derived from amino acids and are found in over 2,500 plant species. Chemically, cyanogenic glycosides are described as glycosides of α-hydroxynitriles (Natesh *et al*., 2018) [23]. Generally, CN acts as a defense mechanism in plants, leading to the release of toxic hydrogen cyanide (HCN), aldehydes or ketones, and glucose compounds (Joshi *et al*., 2020) [16]. Some legumes like kidney beans, red gram, linseed, cassava, and many fruit pits contain cyanogenic glycosides that can release hydrogen cyanide (HCN) through hydrolysis (Akande *et al*., 2019) [67]. HCN is quickly absorbed and some is exhaled, but most is rapidly detoxified in the liver by conversion to thiocyanate. Excessive cyanide ions can cause anoxia in the central nervous system, deactivating the cytochrome oxidase system and leading to death within seconds (Awulachew, 2022) [3]. HCN can result in central nervous system dysfunction, respiratory failure, and cardiac arrest. Inside the body, cyanide inhibits cytochrome oxidase, the final step in electron transport, and consequently blocks ATP synthesis (Sinha and Khare, 2017) [38]. Besides their toxic effects, CN can also serve as mobile nitrogen storage compounds in seeds, which are essential during germination. Cassava is an example of a plant crop rich in cyanogenic glycosides (Bora, 2019) [4].

These are naturally occurring substances that intervene with function of the thyroid gland and are responsible for a disease called goiter. Goitrogens derived from a word "goiter" means hypertrophy of the thyroid gland. On blocking production of thyroid hormones, the gland tried to enlarge to compensate for inadequate hormone synthesis (Sahu *et al*., 2020) [35]. Goitrogens block iodine absorption and thus affect the thyroid function. There are two general categories of foods that have been associated with disrupted thyroid hormone production in humans: soybean-related foods and cruciferous vegetables. Goitrogen-rich foods include vegetables from the genus Brassica, such as broccoli, cabbage, cauliflower, Brussels sprouts, and kale. Triiodothyronine (T_3) and thyroxin (T_4) levels are affected by cruciferous vegetable consumption, resulting in hypothyroidism (Awulachew, 2022) [3]. The goitrogenicity of some compounds is reflected under low iodide status. Therefore, supplementation of iodide in di*et al*leviates the goitrogenic effect. Foods made from soy, such as tofu and tempeh, as well as soy extracts are all included in the category of foods that are related to soybeans. Although soy foods contain a lot of similar chemicals, it is the is flavones in soy that have been linked to lowered thyroid hormone production (Ngo & Tong, 2021) [24].

Table 1: Presence of antinutritional compounds in the respective vegetables

Vegetable	Antinutritional Compound	References
Asparagus	Saponins, Chaline-esterase inhibitor	Dagostin *et al*., 2017 [8]
Beats and Spinach	Oxalates, nitrates, phytate, saponins, nitrosamine	Ertop *et al*., 2017 [57]
Brassicaceae	Glucosinolates, choline-esterase inhibitor, s-methyl cystiene sulfoxides	Oghbae *et al*., 2016. [28]
Carrot	Carota-toxin	Wang *et al*., 2018 [18]
Chillies	Capsaicin	Oghbae *et al*., 2018
Legumes	Lectins, Cyanogenic glucosides, Haemagglutinins, Trypsin, Amylase	Elghali,*et al*., 2019 [11]
Letuce	Nitrates, alkaloids	Gemede *et al*., 2019
Parsley, Celery	Psoralens, Terpenoid, Alkaloids, Cholineesterase inhibitor	Gheorghe *et al*., 2022 [14]
Potato	Solanine and Chaconine	Ngyuen *et al*., 2018[60]
Pumpkin and Squashes	Choline-esterase inhibitor	Nkhata *et al*., 2020[61]
Solanaceous Vegetables	Alkaloids	Joshi, *et al*., 2020 [16]
Sweet Potato	Ipomeamarone	Alam *et al*., 2021[62]

Simply put, an antivitamin is "a chemical that renders a vitamin ineffective. An antivitamin and a vitamin antagonist are essentially the same thing. It is a compound that decreases or completely cancels a vitamin's chemical effect in the body. Raw kidney beans have anti-vitamin E factors that cause liver necrosis and muscle degeneration. Bracker fern contains antivitamin B1. Isolated soya protein has also been found to contain antivitamin E, which is thought to be caused by betocopherol oxidase. An anti-pyridoxine component in linseed inhibits growth (Saluanke, 2018) [56]. Anti-vitamins exhibit properties that are contrary to those of vitamins, disrupting vitamin absorption, metabolism, or functionality and possibly resulting in a deficiency or diminished vitamin efficacy. It's worth highlighting that "anti-vitamins" isn't a common term within the fields of nutrition or biochemistry; instead, specific compounds are recognized as antagonists or inhibitors of particular vitamins. For instance, avidin, a protein in raw egg whites, strongly binds to biotin (a B vitamin), hindering its absorption, but this effect is lessened through cooking. Oxalates, found in foods like spinach and beet greens, can form insoluble crystals when binding to calcium, potentially hindering calcium absorption. Phytic acid (Phytate), present in grains and legumes, can diminish the bioavailability of essential minerals by binding to them. Tannins in tea, coffee, and certain fruits can impede the absorption of minerals, notably iron. Goitrogens, found in select vegetables like cabbage and broccoli, can disrupt iodine uptake by the thyroid gland, possibly leading to thyroid-related complications. Importantly, consuming these compounds in moderation as part of a well-rounded diet is not harmful and can even confer health benefits.

Effect of antinutritional factors on the human body

Anti-nutritional factors have both positive and negative effects on the human body. These factors negatively impact the human body by reducing the digestion, absorption and utilization of nutrient intake. These may also impede growth, performance, and animal health due to a variety of factors, including reduced protein digestibility, nutrient binding, intestinal wall damage, and decreased digestive efficiency. Adverse consequences (Gheorgie *et al*., 2019) [55]. Leads to nutritional deficits interferes with how nutrients are used and function. Antinutritional factors can limit meal components before consumption, during digestion in the gastrointestinal tract, and after absorption inside the body. Expanding beneficial bacterial populations the seeds of Lupinus campestris are anti-mutagenic. Following exposure to plant lectins, heat shock proteins 70 and 90 are down regulated in gut epithelial cells. Lectins in legumes have been found to function as a mucosal adjuvant. Rats that ate warm-treated chickpea experienced a reduction in hypercholesterolemia. The various effect of antinutritional factors on human body are discussed in (Table 2).

Table 2: Antinutritional compounds in vegetables and their adverse effects on human body

Antinutritional compound	Vegetable	Adverse Effect	References
Carota-toxin	Carrot	Neurotoxic symptoms	Lopez *et al*., 2020 [43]
Nitrates, alkaloids	Lettuce	Methaemoglobinaemia	Ahemad *et al*., 2020 [48]
Glucosinolates, choline esterase inhibitor, s-methylcysteine sulfooxides	Brassicaceae	Goiter, digestive disorders	Shatilov *et al*., 2020 [49]
Oxalates, nitrates, phytate, saponins, nitrosamine	Beats and Spinach	Methaemoglobinaemia reduce bioavailability of certain mineral such as Ca, Fe & Zn. carcinogenic	Istiqomah *et al*., 2022 [45]
Ipomeamarone	Sweet Potato	Enzyme inhibitor	Habinshuthi *et al*., 2020 [44]
Serotonin	Watermelon	Elevates blood pressure	Maoto *et al*., 2020 [46]
Choline esterase inhibitor	Pumpkin and Squashes	Neurotoxic	Das *et al*., 2020 [64]
Lectins, Cyanogenic glucosides, Haemagglutinins, Trypsin, Amylase	Legumes	Allergens	Pasqualone *et al*., 2020 [47]
Alkaloids	Solanaceous Vegetables	Birth defects, Protease inhibitors	Mostafidi *et al*., 2020 [50]

Strategies for mitigating anti-nutritional compounds

Removing the antinutritional factors from vegetables are essential to improve their quality. The poor availability of nutrients can lead to several health-related concerns. For instance, phytates present in food are contributory factor for zinc, calcium and phosphorous deficiency. Dietary saponins not only decreases the growth but also interfere with absorption of Vitamin A and E. Due to this antinutritional effect, it is very much important to practice certain measures to reduce their content. Different techniques such as soaking, fermentation, cooking and autoclaving, microwave processing, as well as radiation have become handy to disable the anti-nutrients from vegetables (Popova and Mihaylova, 2019; Samtiya *et al*., 2020) [51, 37].

Soaking is a simple physical method for eliminating soluble anti-nutritional factors. During soaking, water permeates the protein fraction and starch granules, promoting protein denaturation and starch gelatinization, which softens the texture of beans (Awulachew, 2022) [3]. Since phytate is water-soluble, vegetables soaked in water overnight experience a significant reduction in phytates in the soaking water, along with an enhancement of naturally occurring phytase. The loss of phytase occurs due to the leaching of phytase ions into the soaking liquid driven by differences in chemical potential, which govern the diffusion rate (Abbas and Ahmad, 2018) [26].

Fermentation is a vital process for reducing the levels of anti-nutrients in food items and enhancing mineral extractability, protein digestibility, and overall nutritional value. It reduces the quantities of phytic acid, tannins, and polyphenols with the fermentation treatment, subsequently increasing the mineral bioavailability and digestibility of the food. Phytic acid in vegetables is present in complexes with metal cations like Zn, Fe, and Ca (Ertop and Bektaş, 2018) [10]. The decrease in phytic acid during fermentation is attributed to the action of the enzyme phytase released by microorganisms during the fermentation process. As a result, it is advisable to consume vegetables after undergoing fermentation treatment (Gupta *et al*., 2019) [66]. Lactic acid fermentation can also lower tannin levels, leading to improved iron absorption, except in certain high-tannin cereals where minimal or no enhancement in iron availability has been observed (Ray and Didier, 2017) [34]. Antinutrients like phytic acid, tannins, and oxalic acid can be reduced by cooking the vegetables. Because of their protein nature, protease inhibitors are easily denatured by heat. Controlled heating at a temperature less than boiling for at least 15 minutes has been shown to reduce Antinutrients levels. Tannins, phytic acid, hydrogen cyanide, trypsin inhibitors, and oligosaccharides can all be significantly reduced by autoclaving. Cooking sweet potato leaves in lemon juice reduced polyphenols by 56% and lowered oxalate levels (Awulachew, 2022) [3]. Numerous studies have demonstrated that the application of heat during processing enhances the absorption and digestibility of iron, offering both nutritional and health advantages. These heat treatments serve to elevate the nutritional content and overall quality of vegetables. They are employed to improve the protein quality of vegetables by deactivating anti-nutrient factors, particularly trypsin inhibitors and hemagglutinins. It is worth noting that heat treatments result in significant reductions in vitamins, minerals, and certain other soluble compounds, and the temperature at which these treatments are applied plays a crucial role in nutrient availability (Ahmad, 2021) [52].

Microwaves are electromagnetic waves within the frequency range of 0.3 GHz to 300 GHz and are utilized for various food applications by interacting with dielectric food materials. During microwave heating, some of the energy is absorbed while a portion is transmitted and reflected, dissipating as heat (Meda, Orsat, & Raghavan, 2019) [54]. Microwave treatment can partially reduce phytic acid due to its sensitivity to heat and its tendency to form insoluble complexes with other components. Some researchers have found that microwave treatment generates free radicals, leading to decreased inositol and inositol phosphate levels, which, in turn, reduce phytic acid content. The inactivation of trypsin inhibitors is attributed to the denaturation of thermally unstable proteins and the disruption of sulfhydryl and disulfide (-S-S-) groups, which are susceptible to microwave-induced damage. Moreover, tannins, which are water-soluble and thermally unstable, can be reduced by microwave processing when they dissolve in aqueous media upon soaking and are easily degraded. The heat sensitivity of saponins may result in their loss during microwave processing (Suhag *et al*., 2022) [39].

Irradiation is a common method in food processing that minimally affects nutrients, especially proteins, and prevents the formation of indigestible products such as Maillard compounds, which result from the non-hydrolysable bonding between carbohydrates and proteins due to heating. Irradiation effectively eliminates microbial and fungal contaminants from food, removes anti-nutritional elements, and enhances nutrient digestibility. Numerous studies have shown that irradiation is efficient in reducing phytic acid and trypsin inhibitors (Khosravi *et al*., 2021) [17]. Ultrasound is a frequently used form of radiation, characterized by sound waves exceeding 20 kHz, surpassing the upper limit of human hearing. When applied with ample intensity to a product, ultrasound disrupts biological structures, resulting in cellular demise. Ultrasounds, when combined with heat (thermosonication) and pressure (manosonication), have been proven to deactivate microorganisms and enzymes that are resilient to heat (Dagostin, 2018) [7].

Another effective technique for reducing anti-nutrient content in plant-based foods is germination, a process that involves soaking and sprouting seeds or grains. During germination, seeds start to grow, and enzymes within the seeds become activated (Nkhata *et al*., 2018) [27]. One essential enzyme activated during germination is phytase. Phytase is an enzyme that breaks down phytate, the storage form of phosphorus in seeds. Phytate is considered an anti-nutrient because it binds to minerals like calcium, zinc, iron, and magnesium, making them less available for absorption by the human body (Laxmi *et al*., 2018) [18-19]. By breaking down phytate, phytase helps to reduce the levels of phytic acid in the food, subsequently enhancing mineral bioavailability. When seeds germinate, the phytase enzyme becomes more active and effectively breaks down phytate. As a result, the concentration of phytic acid in the germinated seeds decreases. This reduction in phytic acid enhances the bioavailability of essential minerals, making them more accessible and beneficial for human absorption (Oghbaei and Prakash, 2019) [65]. Moreover, germination alters the nutritional composition, biochemical characteristics, and morphological properties of the food. It can enhance the levels of certain nutrients, such as vitamins and amino acids, while reducing anti-nutritional factors like lectins and protease inhibitors. This transformation during germination contributes to improving the overall nutritional quality of plant-based foods (Onyango *et al*., 2019) [30-31].

Reducing antinutritional factors in vegetables is a critical consideration to enhance their nutritional value and overall digestibility. Several techniques are employed to mitigate the presence of these compounds and improve the nutritional quality of vegetables. However, each technique has its limitations, and achieving complete elimination of antinutritional factors can be challenging. Here's a brief introduction to the techniques and their limitations.

To reduce antinutritional factors in vegetables are essential for improving their nutritional value and promoting better digestion. However, it's crucial to acknowledge certain limitations associated with these efforts. Firstly, no technique can entirely eradicate antinutritional factors; they can only be reduced, not eliminated completely (Anguas *et al*., 2021) [2]. Additionally, some processing techniques may inadvertently cause nutrient loss, potentially affecting the overall nutritional quality of the vegetables. Certain methods, such as boiling or blanching, may consume a significant amount of energy and water, rendering them resource-intensive and less environmentally sustainable. Moreover, processing techniques can alter the taste, texture, and appearance of the vegetables, impacting consumer acceptance (Zeumori *et al*., 2021).[70) Lastly, the effectiveness of each technique varies based on the type of antinutritional factor and the specific vegetable, necessitating a thoughtful selection of the appropriate method for each case (Elghali *et al*., 2019) [11].

Conclusion

Vegetables are a crucial part of our diets and are abundant in various essential nutrients, particularly vitamins and minerals. However, certain vegetables also contain harmful substances like Cyanogenic glycosides, protease inhibitors, lectins, tannins, alkaloids, and saponins, which can lead to undesirable effects in humans if their intake surpasses certain limits. Addressing these anti-nutritional elements present in vegetables is of utmost importance to enhance the nutritional value and safety of plant-based diets. Several methods have been employed to mitigate the detrimental effects of these substances and improve the overall nutritional content of vegetables. These methods include soaking, cooking, fermentation, germination, and enzymatic treatment, all designed to decrease anti-nutritional factors like phytates, oxalates, lectins, and protease inhibitors. By doing so, the vital nutrients become more readily available and their absorption is increased. However, it is important to note that each method has its own set of limitations and may not completely eradicate antinutritional factors. Furthermore, the effectiveness of these approaches can vary depending on the specific antinutritional factor and the particular vegetable being processed. Consequently, a combination of diverse techniques and a well-rounded dietary approach are crucial for optimizing nutrient absorption and ensuring a wholesome and balanced diet that promotes overall health and wellness. Continuous research and advancements in food processing techniques are vital to devise efficient strategies for minimizing antinutritional factors in vegetables, ultimately improving the health of the general public.

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