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Review article

A review on microgreens their enzymes, and inhibitor's role on health

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Abstract

Today, the paramount concern for individuals revolves around their well-being; indeed, without good health, little else holds genuine significance. The advent of the SARS-CoV-2 pandemic has significantly altered people's perspectives, fostering a resolute determination to approach dietary choices with heightened awareness and precaution. Microgreens, nutrient-dense seedlings, have garnered significant attention for their potential health benefits. This review delves into the intricate relationship between microgreens, their endogenous enzymes, and naturally occurring inhibitors. We explore the diverse array of enzymes present in microgreens and their catalytic roles in various biochemical processes. Furthermore, we examine the role of enzyme inhibitors within these tiny powerhouses and their potential implications for human health. By understanding the enzymatic landscape of microgreens, we aim to elucidate their impact on key physiological functions, including digestion, metabolism, and antioxidant defense. In a world where science and technology continually set new benchmarks, it becomes our responsibility to prioritize and sustain better health practices, thereby paving the way for improved well-being for future generations. This review provides a comprehensive overview of the current state of knowledge and highlights potential avenues for future research to unlock the full therapeutic potential of microgreens.

Introduction

Microgreens are the seedlings of various vegetables and herbs and are celebrated for their distinctive appearance and concentrated flavors. Physically, microgreens are characterized by their tiny size, usually ranging from 1 to 3 inches in height [1]. They consist of a central stem and two small, unfolded cotyledon leaves, showcasing vibrant colors that can vary depending on the plant type. The texture of microgreens is delicate, and their flavor is often more intense compared to their mature counterparts. Despite their diminutive size, microgreens pack a nutritional punch, containing a concentrated amount of vitamins, minerals, and enzymes, making them a popular and healthful addition to salads, sandwiches, and various culinary dishes [2, 5]. With a clarified understanding of what is a microgreen, we can further explore their internal composition to understand how they positively impact health. To gain a deeper insight, it's essential to understand the significance of enzymes and their crucial role in our health. Leguminous microgreens have a mechanism that can reduce the activity of enzymes as they possess significant inhibitors which are called the enzymatic inhibitors. These inhibitors inhibit the carbohydrate digestive enzymes thus reducing the postprandial hyperglycemia and risk of developing diabetes [2, 4]. In India, between 1995 and 2025, the number of people with diabetes are projected to rise from 19 to 57 million. As per the National Urban Diabetic Survey, the incidence of diabetes was found to be high in cities like Hyderabad 16.6%, Chennai 13.5%, Bangalore 12.4%, Kolkata 11.7%, Delhi 11.6%, and Mumbai 9.3%. Of all these diabetic populations, 80% account for Type 2 diabetes [6].

These nutritional powerhouses have recently gained interest, and is being researched further for cellular metabolic analysis as well their effect on the body. Microgreens are increasingly recognized as functional nutraceutical foods due to their rich nutritional profile. This study encompasses a comprehensive analysis, starting from fundamental aspects like the physical properties of microgreens to identifying and quantifying nutritional components such as antioxidants and phytoconstituents [5] (Figure1).

Figure 1. Fenugreek microgreen.

Growth conditions for microgreens

What makes these microgreens beneficial and nourishing for our bodies? To comprehend the answer, it is crucial to grasp the concept of microgreens. Understanding the various stages of plant development is essential. The growth and development of a plant progress through a series of well-defined stages, encompassing a fascinating journey from the embryonic stage to maturity. In the embryonic stage, the seed undergoes intricate differentiation, giving rise to distinct cells. Notably, the radicle transforms into the primary root, the hypocotyl evolves into the early part of the stem, the cotyledon metamorphoses into seed leaves, and the epicotyl becomes the stem, bearing the plant's first true leaves. Subsequent to the embryonic stage, the germination stage unfolds, consisting of three sub-stages. Initially, the seed undergoes water absorption, a crucial phase known as water inhibition. Following this, radicle emergence transpires as the primary root penetrates the seed coat. Lastly, hypocotyl emergence takes place as the plant stem emerges, initiating the progression toward the seedling stage. The seedling stage is of particular interest, further divided into cotyledon expansion and true leaf development. Upon breaking through the soil, the plant experiences the development of its first true leaves, marking the inception of the microgreen stage. This phase signifies that the plant has met the criteria to be considered a microgreen, allowing it to be harvested, typically occurring within a span of 7-21 days post-germination [3, 10].

On the bright side, more people are directing microgreens as potential functional foods, attributed to their significant micronutrients and bioactive compounds [11, 21, 22]. They are popular due to their diverse and appealing colors, textures and flavors. The extensive variety of species and cultivars suitable for microgreen cultivation, coupled with the ability to regulate their growth conditions even in micro-scale production, underpins their promising potential for customized nutrition. This also enables targeting specific consumer groups with particular dietary preferences [3], such as vegans or raw-foodists. Simultaneously, microgreens can be cultivated in a straightforward manner, even in limited spaces, making them suitable for urban agriculture and potential components of space life support systems [12].

Microgreens can be harvested just after or during the cotyledon stage which is the initial stages of the seedling development. During this period, the immature leaves also called the cotyledon emerges from the seed and just when two leaves grow marks the characteristic of a microgreen. This usually happens between 7-21 days, however depending on the specific species being cultivated, some may grow faster, yet others may take time to grow [5]. Microgreens are smaller than baby greens and harvested later than sprouts. The primary distinction between sprouts, baby greens, and microgreens lies in the timing of harvest. Baby greens are typically harvested when they reach a height of 2 to 4 inches and have been growing for 15 to 40 days, whereas microgreens are harvested immediately after their youngest leaves emerge [23]. Furthermore, sprouts can be distinguished from microgreens by their composition; sprouts include the seed, root, and stem, while microgreens are harvested without the roots [5]. This variance in growing duration between sprouts or baby greens and microgreens contributes to the delicate textures and distinct flavors characteristic of microgreens. Harvesting microgreens at the cotyledon stage ensures that they are at their peak flavor and nutrient content while still maintaining their tender texture. It is no doubt that the consumption of microgreens has witnessed a notable surge owing to their elevated levels of vital bioactive compounds such as vitamins, minerals, and antioxidants, which play pivotal roles in human health [17].

Post-harvesting techniques involved for microgreens

Microgreens require certain post-harvesting procedures to preserve their marketability, shelf life, and nutritional value. Growing flats full of different media, such as potting mixes, peat-based substrates, hydroponic systems, or creative techniques like recycled textile fiber mats, are commonly used to cultivate microgreens in controlled conditions like greenhouses. In order to limit damage and prevent contamination, the harvesting process demands efficiency and care, in addition to clean, sharp instruments.

During harvesting in order to prevent damaging of the roots the stem is chopped slightly above the growing media. Microgreens are carefully washed under running water to get rid of any last bits of dirt, debris, or other pathogens. Appropriate drying methods are necessary to avoid too much moisture, which can cause spoiling quickly. Microgreens can be kept in regulated conditions to increase their shelf life without affecting their flavor, nutritional content, or aesthetic appeal after they have dried. In order to extend the shelf life of harvested microgreens proper storage conditions are necessary. This is achieved by lowering the storage temperature, proper packing, preserving by edible coatings, use of antimicrobial agents etc.

Microgreens as potent functional foods

Microgreens offer a variety of vitamins, presenting an additional health benefit that can be seamlessly incorporated into one's diet. Among the notable vitamins found in microgreens are Vitamin C, abundant in broccoli and kale microgreens, and red cabbage microgreens. Vitamin C acts as a potent antioxidant, safeguarding cells from damage, fortifying the immune system, and contributing to the synthesis of collagen for healthy skin and connective tissues. Another crucial vitamin, Vitamin K, is prevalent in microgreens such as kale, spinach, and beet microgreens. Vitamin K plays a pivotal role in blood clotting, bone health, and calcium regulation within the body. Additionally, microgreens like carrot, kale, and Swiss chard microgreens are rich sources of Vitamin A, particularly in the form of beta-carotene. Vitamin A supports vision health, immune function, and skin integrity [10].

Microgreens such as sunflower, pea shoots, and radish microgreens offer Vitamin E, acting as antioxidants to protect cells from oxidative stress and promote skin health. Furthermore, a spectrum of B vitamins is found in microgreens like sunflower, broccoli, and alfalfa microgreens [10]. Each B vitamin plays a distinctive role in supporting energy metabolism, growth, red blood cell production, brain development, DNA synthesis, and overall cellular function. For instance, the leguminous microgreens, especially *Phaseolus vulgaris* L. (Kidney bean) had the most concentrated amounts of phenols [9, 18], which is one of the bioactive compounds that aid in regulation of metabolism, weight, preventing chronic diseases and cell proliferation. Moreover, they have therapeutic effects in cardiovascular diseases [13, 25].

This nutrient diversity in microgreens extends to include B1 (Thiamine), B2 (Riboflavin), B3 (Niacin), B5 (Pantothenic Acid), B6 (Pyridoxine), B9 (Folate), and B12 (Cobalamin). For instance, B12 is crucial for nerve function and red blood cell formation. Incorporating a variety of microgreens into one's diet offers a comprehensive range of vitamins, promoting optimal health and well-being [10, 14, 26]. With their nutrient-rich composition, microgreens emerge as not only a flavorful addition to culinary endeavors but also as a powerhouse of essential vitamins supporting various physiological functions within the body. Microgreens possess substantial potential to enhance the nutritional quality of the human diet, owing to their abundance of beneficial compounds. Additionally, they are garnering increasing interest not only for their nutritional value but also for their captivating organoleptic attributes and commercial viability [3].

Various nutrients, macro/ micro-elements and phytochemicals present in various microgreens

Microgreens, young edible seedlings of various vegetables and herbs, are increasingly recognized for their dense nutrient profile, particularly their high content of micro and macronutrients. These nutrients include essential elements like iron (Fe), zinc (Zn), potassium (K), calcium (Ca), nitrogen (N), phosphorus (P), sulfur (S), manganese (Mn), selenium (Se), and molybdenum (Mo) [5]. The high concentration of these nutrients in microgreens is crucial for various bodily functions like oxygen transport or energy production that depends on the presence of iron, other such examples include zinc, which plays a key role in immune function and protein synthesis, while calcium is essential for bone health and muscle function. The presence of potassium helps regulate fluid balance and nerve signals, and phosphorus is critical for energy metabolism and the formation of DNA. Additionally, sulfur contributes to detoxification processes, and selenium and molybdenum are important for antioxidant defense and enzymatic reactions, respectively [1].

In addition to their rich mineral content, microgreens are abundant in a wide array of bioactive phytochemicals, compounds that have significant potential to enhance human health and prevent diseases. Among these, ascorbic acid (Vitamin C) stands out for its role in boosting the immune system, aiding in collagen synthesis, and functioning as a potent antioxidant that neutralizes harmful free radicals. Phylloquinone (Vitamin K1), another important compound found in microgreens, is essential for blood clotting and bone health. α-Tocopherol (Vitamin E) is known for its antioxidant properties, protecting cells from oxidative damage and supporting immune function. [1, 3, 5]

Microgreens also contain high levels of β-carotene, a precursor to Vitamin A, which is crucial for maintaining healthy vision, skin, and immune function. Phenolic antioxidants, another significant component of microgreens, are secondary metabolites that protect plants from environmental stressors and, when consumed, offer anti-inflammatory and anti-carcinogenic benefits to humans. These antioxidants are linked to reduced risks of chronic diseases, such as heart disease and cancer, due to their ability to prevent oxidative stress and inflammation. [5, 13, 16, 17, 24, 25]

Carotenoids, a class of pigments that includes β-carotene, lutein, and zeaxanthin, are also present in substantial amounts in microgreens. These compounds are not only important for plant health, contributing to photosynthesis

and protection against UV damage, but they also provide significant health benefits to humans. For instance, lutein and zeaxanthin are known to protect against age-related macular degeneration, a leading cause of blindness [5].
Anthocyanins, the pigments responsible for the red, purple, and blue colors in many microgreens, possess strong antioxidant and anti-inflammatory properties. These compounds have been shown to improve cardiovascular health, enhance cognitive function, and protect against certain types of cancer. Moreover, glucosinolates, sulfur-containing compounds found in microgreens, are particularly noted for their role in cancer prevention. When consumed, glucosinolates are broken down into biologically active compounds, such as isothiocyanates, which have been shown to inhibit the growth of cancer cells and promote the elimination of potential carcinogens from the body [5, 16, 17, 25].
Microgreens are a potent source of essential micro and macroelements, crucial for maintaining overall health, supporting metabolic functions, and even aiding in the body's defense mechanisms, such as those involved in combating illnesses like COVID-19. The significance of micro and macro-nutrients is substantial. Sodium and potassium, for example, are vital for fluid balance and the proper functioning of nerves and muscles. Calcium and magnesium are essential for bone health and numerous enzymatic processes, while zinc and copper play crucial roles in immune response and antioxidant protection. Iron, on the other hand, is indispensable for oxygen transport and energy metabolism [1, 5].
A study in 2020 [3] underscored the rich mineral composition of specific microgreens, such as cauliflower, broccoli, and broccoli rabe, all members of the Brassica family. Their research demonstrated that these microgreens, grown under varying nutrient conditions, were abundant in essential minerals, including sodium, copper, manganese, calcium, magnesium, potassium, zinc, and iron. These microgreens were also found to contain high levels of macroelements like proteins, dietary fiber, α-tocopherol (Vitamin E), and β-carotene, enhancing their overall nutritional value [3, 5].

Role of enzymes and their inhibitory activity

Enzymes are omnipresent, existing in both our bodies and the food we consume, facilitating the digestion and absorption processes. Functioning as biological catalysts, enzymes act like miniature assistants within our bodies, expediting essential chemical reactions. Each enzyme is assigned a specific task to accelerate the metabolic processes. For instance, during food consumption, enzymes break down substances into smaller components that our bodies can utilize. Without enzymes, these processes would be significantly delayed or may not occur at all. Consequently, enzymes play a pivotal role in ensuring the smooth functioning of our body's processes. It's surprising that these proteins are also present in microgreens, making them a compelling option for inclusion in our diet and harnessing the benefits of these enzymes in our bodies.
Microgreens are considered nutraceuticals since they aid in extra health benefits beyond their nutritional value. Enzymes such as the alpha amylase and the alpha glucosidase are primarily responsible for increasing the post prandial glucose level by aiding in the breakdown of complex carbohydrates into smaller soluble molecules that are easily absorption by the microvilli brush border of the small intestines and ultimately into the bloodstream. In particular, glycosidic linkages of α-D-(1, 4) in carbohydrates are cleaved by α-amylase to produce oligosaccharides, these are then further cleaved to monosaccharide glucose molecule by α-glucosidase. This shows how both the enzymes interwine and play a crucial role in digestion. However, they are also of great concern for patients suffering with metabolic disorders like type 2 diabetes [4, 13] (Figure 2). This is because the increase in absorption of these soluble sugars will in turn cause a spike in the glucose level, which will lead to consequences like hyperglycemia [4, 7, 13].

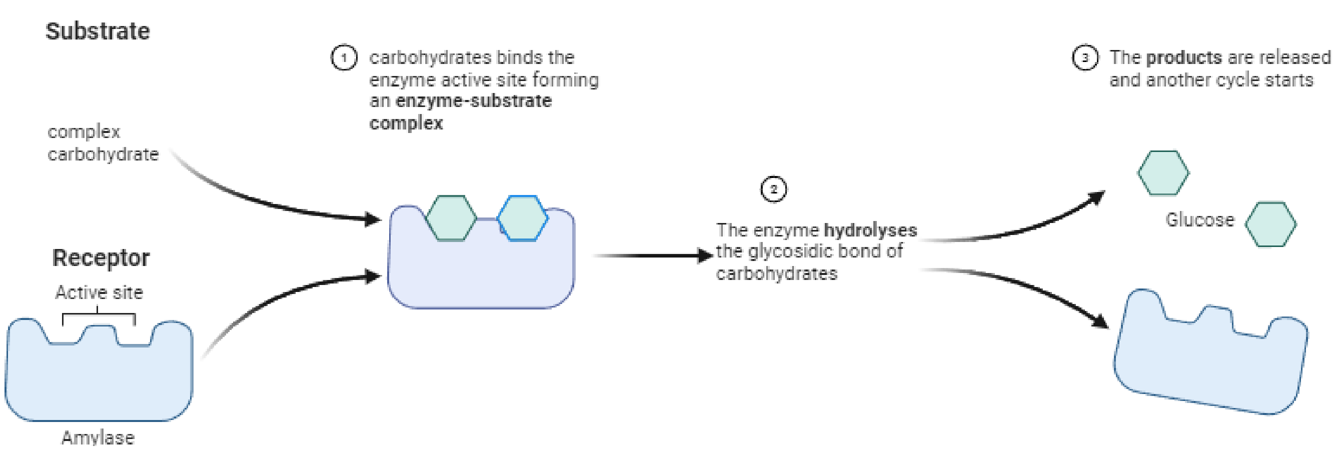

Figure 2. Mechanism of amylase action.

Various microgreens were studied for enzyme inhibitory effect specifically considering leguminous microgreen as the chosen candidate which shows the highest contributor for the presence of alpha amylase inhibitors as well as alpha-glucosidase inhibitors. Acarbose is one of the enzymatic inhibitors found easily in the market that is used for controlling postprandial hyperglycemia. However, due to its gastrointestinal side effects like bloating, diarrhea, and abdominal pain, [15] it is not advisable to use it on a long-term basis. This drives the need to incorporate leguminous microgreens in the diet as they naturally possess inhibitory activity against enzymes like alpha amylase and alpha glucosidase.

One important enzyme that can be found predominantly in several microgreen is the myrosinase enzyme. Myrosinase is primarily associated with cruciferous vegetables, such as broccoli, cabbage, and mustard, which contain compounds called glucosinolates [14]. When these vegetables are chewed or damaged, myrosinase comes into contact with glucosinolates, leading to the formation of various bioactive products, including isothiocyanates, nitriles and other derivatives. Isothiocyanates or ITCs are highly reactive organosulphur phytochemicals that are present mainly in cruciferous vegetables (dark leafy vegetables such as broccoli, watercress, kale, cabbage). They exhibits biological activity such as anti-cancer, anti-inflammatory, and neuroprotective properties. ITCs may also modulate the expression and activity of biotransformation enzymes that are involved in the metabolism and elimination of xenobiotics from the body. These ITCs may help inhibit the development of cancer by interfering with various stages of carcinogenesis, including the initiation, promotion, and progression of cancer cells.

The main cause of obesity is due to the imbalance ratio of energy expenditure and calorie intake, not only that but it is the shift to consumption of high sugary drinks and food with high fats, low fibers and micronutrients that lead to the condition called obesity. This is further linked with other serious life-threatening consequences like increased chances of cardiovascular diseases, hypertension, and Type II diabetes [13]. The most straightforward approach to treating this condition of obesity, one can either reduce the calorie intake or do more physical activities. But if we look deeper into the metabolic mechanism, there is a third option to reduce obesity by reducing the absorption of carbohydrates in the small intestine [2, 4, 15] through inhibiting enzymatic activity namely, α-Amylase and glucosidase.

Amylase enzyme is one of the major secretory enzymes present in the salivary glands as well as the pancreas, playing a crucial role in digestion of complex carbohydrates into smaller oligonucleotides (usually 6-8 glucose units) by cleavage of α-D- (1–4) glycosidic bonds. These are usually called dextrins [18]. The other enzyme present in the small intestine, specifically the intestinal lining brush border; glucosidase further catalysis the breakdown of these oligonucleotides into shorter monosaccharides that can no longer be hydrolyzed and the resulting sugar is absorbed into the intestinal walls and into the blood stream.

In order to inhibit these α-Amylase and glucosidase activity, there are naturally present inhibitory compounds present in plants such as *Phaseolus vulgaris L.* These inhibitory compounds act as defense chemicals from biotic stress [18]. These natural inhibitors act on the enzyme are these inhibitory compounds can be classified into different classes: the knottin-like type, the Kunitz type, the thaumatin-like type, the γ-thionin-like type, the cereal type, and the lectin-like type [19]. These inhibitors are generally recognized as safe with no side effects found compared to the other plant inhibitors [19].

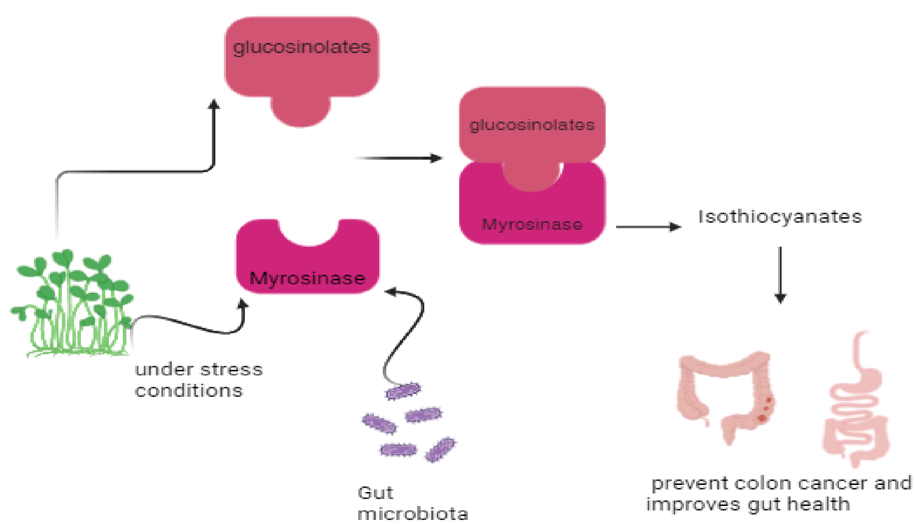

Figure 3. Mechanism of action of myrosinase.

Sulforaphane, an isothiocyanate derived from glucoraphanin, inhibit Phase I enzymes, responsible for activation of carcinogens, and induce Phase II detoxification enzyme systems, thereby increasing the body's cancer defense mechanisms [20, 24]. Myrosinase present in microgreens and the gut microbiota of humans plays a role in metabolizing glucosinolates. Gut bacteria can metabolize the products of myrosinase activity, influencing the bioavailability and biological effects of these compounds. The consumption of cruciferous vegetables and the bioactive compounds such as sulforaphanes formed from myrosinase activity have positive effects on gut health such as reducing the risk of cancers, including colorectal cancer. Nevertheless, the activity of myrosinase and the metabolism of glucosinolates can vary among individuals based on factors such as genetics, diet, and the composition of their gut microbiota [25]. Isothiocyanates, have also been investigated for their potential to modulate the gut microbiota and exert anti-inflammatory effects (Figure 3).

Role of microgreens in improving gut health

The gut harbors the largest microbiome in the human body. Disruption of the mucous barrier that lines up the gut, results in the migration of mucosal tissues, subsequently eliciting inflammation and immune responses. Furthermore, the microbial composition may undergo ongoing alterations throughout adulthood, influenced by factors such as diet, environmental exposures, antimicrobial usage, medications, and aging [27]. Legumes are considered a good source of macro and micronutrients, antinutritional factors and phytochemicals. The interaction between nutrients and the antinutritional factors hinder in the release of nutrients such as the trypsin inhibitors that reduce the bioavailability of protein digestibility and mineral release [5, 28]. Legumes are a good source of these inhibitory compounds, which include Bowman-Birk inhibitors and Kunits- type inhibitors that are known to negatively affect the protein digestion by blocking and binding to protein-hydrolyzing enzymes like trypsin and chymotrypsin by competitive binding. These digestive enzymes are naturally present in the gastrointestinal system [8]. This inhibitory effect may be beneficial with relation to the gut related anti-inflammatory as well as chemo preventive activities in vitro and in vivo, which overall aid in decreasing symptoms of bowel-related problems by mitigating inflammation and gastric pain [29]. For example, in conditions like ulcerative colitis (UC) these protease inhibitors present abundantly in the Fabaceae family contribute in the therapy of UC. As a result of these Protein Inhibitors (PIs), accumulation of the undigested proteins and slower rate of gastric emptying may aid in controlling appetite and managing food consumption, thereby addressing the issue of obesity [7, 8, 14].

A reduction in protein digestibility by PIs could lead to increased levels of undigested protein reaching the colon, where they undergo fermentation by gut microbiota. Some resulting products of peptide and amino acid fermentation may act as precursors for short-chain fatty acids (SCFAs) like butyrate and propionate, known for their beneficial effects on human health. However, it's worth noting that SCFAs are typically derived from dietary carbohydrates, and the health implications of SCFAs derived from amino acids are not as well understood [8]. Ceuleers H *et al.* have found that there are elevated levels of protease activity in the intestinal muscosa of the GI tract in individuals with Irritable Bowl Syndrome (IBS), [29] thus the incorporation of microgreens such as the leguminous microgreens will aid in providing the protein inhibitors that will reverse the mechanism of IBS as well as inflammatory state of UC by preventing release of oxygen free radicles from damaged cells.

In a study conducted in 2017, examined 25 various microgreens to find out the various nutritional components and their comparative analysis among their samples [17]. They found out, Vitamin K also known as phylloquinone are essential for blood coagulation and bone remodeling. These are typically found in dark-green vegetables like spinach, kale, and broccoli, phylloquinone concentrations vary widely among different microgreens, ranging from 0.6 to 4.1 μg/g fresh weight (FW). Garnet amaranth exhibited the highest phylloquinone concentration at 4.1 μg/g, while magenta spinach had the lowest at 0.6 μg/g. Interestingly, microgreens with green or bright red colors generally contained higher phylloquinone concentrations (2.8−4.1 μg/g), whereas yellow-colored microgreens had relatively lower concentrations (0.7−0.9 μg/g). Notably, despite their similar appearance to garnet amaranth, magenta spinach had the lowest phylloquinone concentration [10, 26, 30]. Comparatively, phylloquinone values in microgreens are relatively high when contrasted with those in mature vegetables. For instance, mature amaranth, basil, and red cabbage had phylloquinone concentrations of 1.14, 0.41, and 0.04 μg/g FW, respectively [30].

Ascorbic acid, or vitamin C, is another essential nutrient for human health. Measurements of total ascorbic acid (TAA), free ascorbic acid (FAA), and dehydroascorbic acid (DAA) were conducted in various microgreens, revealing TAA concentrations ranging from 20.4 to 147.0 mg/100 g FW. Red cabbage exhibited the highest TAA concentration, while sorrel had the lowest. Comparatively, red cabbage microgreens had six times higher vitamin C concentrations than mature red cabbage. Similarly, garnet amaranth demonstrated significantly higher TAA concentrations compared to its mature counterpart. While some microgreens, such as golden pea tendrils and sorrel, exhibited lower TAA concentrations, most had higher TAA concentrations than their mature counterparts. [5,10,26, 30].

Tocopherols and tocotrienols, belonging to the vitamin E family, exist in four isomer forms: α, β, γ, and δ. α-Tocopherol is the most active form, while γ-tocopherol is the most abundant in plants. The green daikon radish displayed the highest tocopherol concentrations in both α (87.4 mg/100 g FW) and γ (39.4 mg/100 g FW) forms.

Additionally, cilantro, opal radish, and peppercress microgreens exhibited high concentrations of α- and γ-tocopherols. Despite having lower tocopherol concentrations than mature spinach leaves, golden pea tendrils still contained higher values, indicating their nutritional significance [5, 10, 17]. Under abiotic stresses, tocopherols exhibit variability in their levels, indicating their pivotal function as antioxidants and as markers of stress tolerance in plants. Genetic studies have uncovered that tocopherols' roles extend beyond antioxidant properties, with evidence suggesting involvement in cell signaling pathways. Brassicas also produce phenolics, tocopherols and peculiar seed oils [16]. Consuming Brassica greens has been linked to a decreased likelihood of developing colorectal, stomach, pancreatic, lung, breast, and ovarian cancer [7, 8, 13, 16].

Carotenoids, such as β-carotene, are pigments found in fruits and vegetables, imparting a red-orange color. Renowned as a precursor of Vitamin A, β-carotene plays crucial roles in vision and development, in addition to functioning as an antioxidant due to its molecular structure. Analysis of β-carotene concentrations across 25 microgreens revealed significant variations. Red sorrel exhibited the highest concentration at 12.1 mg/100 g FW, while both golden pea tendrils and popcorn shoots displayed the lowest concentration at 0.6 mg/100 g FW [10, 16]. Notably, cilantro microgreens contained 3-fold more β-carotene than their mature counterparts, with a concentration of 11.7 mg/100 g FW. Furthermore, red cabbage microgreens demonstrated approximately 260-fold higher β-carotene concentrations compared to mature red cabbage. With few exceptions, most microgreens proved to be rich sources of β-carotene, solidifying their status as excellent dietary sources of this essential nutrient [10].

Among the seven carotenoids present in the human body, lutein and zeaxanthin are particularly significant, as they are found in blood and are the only carotenoids present in the retina and lens of the eye. Serving as antioxidants, lutein and zeaxanthin play a crucial role in protecting the eyes from UV light. Cilantro microgreens exhibited the highest concentration of lutein/zeaxanthin at 10.1 mg/100 g FW, while popcorn shoots displayed the lowest concentration at 1.3 mg/100 g FW. Compared to mature cilantro and red cabbage, cilantro and red cabbage microgreens boasted substantially higher concentrations of lutein/zeaxanthin, indicating their potential as superior dietary sources [5,10].

Violaxanthin, another natural carotenoid found in plants, can be converted to zeaxanthin via the xanthophyll cycle. Among the 25 microgreens analyzed, cilantro microgreens demonstrated the highest violaxanthin concentration at 7.7 mg/100 g FW, while popcorn shoots exhibited the lowest concentration at 0.9 mg/100 g FW. Like other carotenoids, most microgreens displayed elevated concentrations of violaxanthin, further underlining their nutritional value [5, 10].

The antioxidant properties of flavanols, a subclass of flavonoids found naturally in plants, and catechins have led to suggestions that their consumption could potentially prevent atherosclerosis. The relatively low incidence of heart disease in France has been attributed to the high consumption of flavonoids from red wine [25, 28].

Conclusion

The comprehensive analysis of various microgreens conducted in this study highlights their significant potential as valuable sources of antioxidants, minerals, vitamins, and other essential nutritional compounds. Microgreens contain a variety of enzymes, and their composition varies among different types of microgreens. Incorporating such microgreens into our diet can similarly offer us nutritional benefits. An illustrative instance highlighting the significance of enzymes is evident in kidney beans, which are also among the microgreen sources utilized in this experiment. The enzyme esterase present in kidney beans facilitates the hydrolysis of triglycerides—a process akin to the action of pancreatic lipase found in the body. Pancreatic lipase, secreted from the pancreas into the small intestine, accelerates the breakdown of triglycerides into fatty acids and glycerol, thereby enhancing the absorption of fats in the intestines and contributing to the digestive process of fats in the gut.

The presence of phytochemicals and antioxidant properties in leguminous microgreens not only holds significant health benefits but also carries economic implications. The utilization of these bioactive compounds in functional foods, dietary supplements, and pharmaceutical formulations can potentially contribute to the growth of industries focused on health and wellness products.

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Competing interests

The authors declare no competing interests.

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Ethics approval and consent to participate

There are no ethical issues related to the conducted study.

Data availability

All data generated or analyzed during this study are included in this published article.

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