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The Palliative Role of Microgreens in Non-communicable Diseases

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Abstract

Microgreens are tender, nutrient-dense seedlings that are recognised for their superior concentrations of vitamins, minerals, and bioactive compounds compared to their mature counterparts. This paper comprehensively explores the diverse aspects of microgreens, including cultivation techniques, nutrient composition, phytochemical profiles, health benefits and their role in non-communicable diseases such as cancer and diabetes. Influence of growth substrates, lighting strategies, and postharvest practices on the nutritional quality and shelf life of microgreens. The presence of functional compounds such as glucosinolates, flavonoids, phylloquinones and anthocyanins strengthens their therapeutic potential against chronic diseases, including cancer, cardiovascular disease, obesity, and diabetes. Even though growing microgreens faces challenges like short shelf life, safety issues, and a lack of standard growing practices, research continues to highlight their importance in promoting healthy and sustainable diets. To make the most of their benefits, future studies should focus on improving how they are grown, finding ways to keep them fresh for longer, and ensuring safe handling practices so they can be more widely used in everyday diets. Research on microgreen supplementation is essential to evaluate their efficacy in the prevention and management of non-communicable diseases.

Major Findings: Microgreens provide higher levels of essential nutrients and bioactive compounds than mature plants. Consumption of microgreens provides various health benefits such as protecting heart health, maintaining blood sugar level and reducing inflammation.

Keywords: Antioxidant, Functional Food, Growth Medium, Microgreens, Therapeutic Nutrition

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1. Introduction

People today are more focused on living healthier lives, which has increased interest in eating foods that are not only tasty but also support overall health and well-being. Plant-based diets, enriched with a huge variety of bioactive compounds, have been widely recognised for their positive effects on human health. These phytochemicals contribute significantly to disease prevention, reinforcing the strong correlation between plant-rich nutrition and reduced incidence of various health disorders[1]. Over the past decade, there has been a noticeable global shift in consumer preferences toward fresh, health-promoting, and functional foods, including sprouted seeds and microgreens. These foods not only offer substantial nutritional benefits but also appeal to consumers seeking novel and flavourful dietary options. Additionally, from a production standpoint, microgreens present a highly favourable crop choice due to their low input requirements and rapid growth cycle, allowing for quick harvesting and market readiness[2].

Microgreens are typically harvested when they reach a height of approximately 1 to 3 inches, depending on the plant species, and this generally occurs between 7 and 21 days after sowing. Compared to sprouts, microgreens are often regarded as superior, due to their enhanced nutritional profile and more characteristic

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flavour. Additionally, they have been found to possess higher concentrations of vitamins, minerals, and phytochemicals than their mature parts[3].

The origins of microgreens can be traced back to the 1930s, when pharmacies in northern regions cultivated, dried, and marketed wheatgrass for its medicinal properties. By the 1960s, crops like sunflower, buckwheat, and radish were occasionally grown indoors during winter, while the 1970s saw a rise in the popularity of homemade "grasses" due to their perceived health benefits. In the 1980s, culinary professionals began cultivating young greens such as cresses and seedlings for decorative use in fine dining. The term "microgreens" gained broader recognition in the United States around 1998. In the following decade, particularly during the 2000s, local farmers across North America began supplying microgreens to numerous retail outlets. Today, these tender greens have a common place in grocery stores and are appreciated by consumers for their appealing texture and flavour. Their growing popularity is largely attributed to their distinct sensory qualities and high concentrations of health-promoting compounds, including vitamins, minerals, and antioxidants, comparable to or exceeding those found in mature leafy vegetables[4]. The term "microgreens" refers to the tender, immature stages of various vegetable plants. Today, their cultivation has expanded globally, with numerous greenhouses actively producing these nutrient-rich greens. Since the introduction of the concept of "functional foods" in the early 2000s, microgreens have gained significant recognition for their contributions to health promotion and longevity. Presently, they are widely integrated into agricultural systems to produce diverse value-added products. The rising incidence of chronic diseases has intensified the search for innovative agricultural strategies that support public health. The growing momentum of urban agriculture, especially within controlled environments, reflects the demand for food sources that are not only nutrient-rich but also locally accessible and sustainable. Within this context, microgreens have received significant attention due to their distinctive biological traits, high nutritional value and locally accessible, positioning them as a promising contributor to human health[5]. This review seeks to address current knowledge gaps by consolidating recent research on various aspects of microgreens, including their classification, cultivation substrates, light conditions, nutrient composition, health-promoting properties, consumer preferences, and emerging market dynamics.

2. Botanical Classification of Microgreens

Microgreens originate from a wide spectrum of plant families, each contributing distinct sensory attributes, growth characteristics, and nutritional profiles. Classifying them according to their botanical families provides a systematic framework to understand their diversity and functional value. Families such as Brassicaceae, Amaranthaceae, Apiaceae, Fabaceae, and Lamiaceae are among the most common sources, offering unique colours, flavours, and bioactive compounds. Table 1 presents the botanical classification of commonly cultivated microgreens.

3. Production and Cultivation Techniques

3.1 Growth Substrates and Conditions

There are variety of mediums are available to grow microgreens. Natural amendments refer to organic materials incorporated into growing media to enhance plant growth and improve yield quality.

Table 1. Botanical classification of commonly cultivated microgreens

S. No.	Botanical Family	*Scientific Name*	Common Name	References
1	*Amaranthaceae*	*Amaranthus caudatus*	Foxtail amaranth	5
		Beta vulgaris	Beet	2
		Fagopyrum esculentum	Buckwheat	2
		Chenopodium quinoa	Quinoa	5
2	*Amaryllidaceae*	*Allium fistulosum L.*	Scallion	6
		Allium Sativum	Garlic	2

Table 1. Continued...

S. No.	Botanical Family	*Scientific Name*	Common Name	References
3	*Apiaceae*	*Coriandrum sativum*	Coriander	5
		Daucus Carota L.	Carrot	2
		Foeniculum vulgare	Fennel	2
		Anethum graveolens	Dill	5
4	*Araliaceae*	*Panax ginseng*	Korean ginseng	5
5	*Asteraceae*	*Lactuca sativa*	Lettuce	5
		Cichorium intybus	Chicory	2
		Helianthus annuus L.	'Blackoil' sunflower	6
6	*Boraginaceae*	*Borago officinalis L.*	Borage	6
7	*Brassicaceae*	*Eruca sativa (Mill.) Thell.*	Arugula	6
		Brassica oleraceaL.var. Italica Plenck	Broccoli	6
		Brassica oleracea var. acephala	Kale	5
		Raphanus sativus	Radish	2
		Brassica oleraceaL.var. capitata	Red cabbage	7
		Lepidium sativum L.	Cressida Cress/Garden Cress	6
		Brassica napus L.var. pabularia(DC.)	'Red Russian' kale	6
		Brassica rapa L.var. japonica	Mizuna 'America'	6
		Brassia juncea (L.) Czern.	'Garnet giant' mustard	6
		Raphanus sativus L.	'Red arrow' radish	6
8	*Cucurbitaceae*	*Cucurbita moschata*	Pumpkin	5
		Cucumis sativus	Cucumber	2
		Lagenaria siceraria	Bottle gourd	5
9	*Fabaceae*	*Pisum sativum L.*	Green pea	5
		Lens culinaris Medicus	Lentil	5
		Glycine max	Soybean	5
		Trigonella foenum-graecum	Fenugreek	2
		Vigna radiata	Mung bean	5
10	*Lamiaceae*	*Ocimum basilicum L.*	'Dark opal' basil (Red)	6
		Perilla frutescens (L.) Britton	Britton shiso	6
		Salvia hispanica	Chia	2
		Melissa officinalis L.	Lemon balm	6
11	*Leguminosae*	*Cicer arietinum L.*	Chickpea	2
12	*Linaceae*	*Linum flavum*	Golden flax	5
13	*Malvaceae*	*Abelmoschus esculentus*	Okra	8
		Corchorus olitorius	Jute mallow	5
14	*Pedaliaceae*	*Sesamum indicum L.*	Black sesame	5
15	*Poaceae*	*Triticum aestivum*	Wheatgrass	9
		Zea mays	Corn	10
16	*Portulacaceae*	*Portulaca oleracea*	Purslane	2
17	*Solanaceae*	*Lycopersicon esculentum*	Tomato	11
		Solanum melongena	Egg plant	12

These substances function by modifying the physical and chemical properties of the substrate and boosting its biological activity. Common examples include compost, vermicast, humic substances, animal manures, and sawdust. They contribute essential macro and micronutrients, foster beneficial microbial communities, increase the medium's water retention and aeration, and facilitate better nutrient availability essential for plant development[13].

Microgreens can be cultivated using a diverse range of growing media. Greenhouse practices vary considerably, with some producers preferring substrates such as perlite or vermiculite, while others utilise soil-less mixes specifically formulated for controlled environments. Peat-based blends and synthetic growing mats are commonly adopted by commercial growers. Combinations of sand and vermiculite, as well as composts derived from materials such as peat, coconut coir dust, sugarcane filter cake, and vermicompost, have been investigated for growing medium. Research demonstrated that these various media types are all effective in supporting the successful cultivation of microgreens[5] (Figure 1).

3.1.1 Soil Medium

Despite advancements in soilless cultivation systems, soil-based methods remain the most employed technique in agricultural production. Soil-based cultivation remains a widely used method for growing microgreens, with soil pH and porosity playing critical roles in nutrient uptake and water availability. Neutral pH and loose-textured soils enhance growth and antioxidant levels, particularly in species like red amaranth. In Black soil, due to its lower compaction, it supports better development compared to yellowish-brown and orange soils. Compost addition further improves nutritional quality. However, some soil components may challenge food safety risks, requiring careful selection. Soil properties significantly influence the yield and functional value of microgreens[14].

3.1.2 Hydroponics Medium

The global decline in fertile land and increasing freshwater scarcity have contributed to the growing adoption of indoor vertical farming systems. Hydroponics is a soilless cultivation technique in which plants are grown in water or nutrient-enriched solutions, allowing for direct and efficient uptake of essential minerals and elements required for growth. Among modern cultivation technologies, hydroponics has gained widespread application in urban agriculture. Compared to traditional soil-based methods, hydroponic systems offer distinct advantages, making them particularly well-suited for vertical farming environments[15,16]. Conversely, it is important to recognise that multiple studies have indicated higher microbial safety concerns associated with hydroponically grown sprouts and microgreens compared to those cultivated in alternative substrates[14].

3.1.3 Aeroponics Medium

Aeroponics represents another innovative cultivation technique well-suited for vertical farming systems. This method eliminates the use of soil or any solid substrates by suspending plant roots within an enclosed chamber, where they are periodically misted with water and nutrient solutions via atomization. The exposure of roots to a highly oxygenated environment, combined with fine water droplets, enhances nutrient absorption and root respiration. Remarkably, aeroponics requires only about 10% of the water used in traditional hydroponic or soil-based cultivation systems, making it an exceptionally water-efficient alternative[17].

3.1.4 Hydrogel

Hydrogels are three-dimensional polymeric networks capable of absorbing and retaining large quantities of water, allowing them to remain hydrated over extended periods. In recent years, they have gathered considerable interest for various innovative applications in the fields of food and agriculture, including their use as soil conditioners, seed coatings, controlled-release fertilisers, and agents for removing dyes, specific pollutants, and bacteria. As a substrate for microgreen cultivation, hydrogels present a promising solution for enhancing water efficiency by reducing irrigation frequency. Moreover, their ability to facilitate the slow release of nutrients and antimicrobial compounds offers potential to create a sustained, nutrient-rich, and pathogen-resistant growing environment[14,18].

3.1.5 Spent Mushroom Compost

The mushroom industry generates substantial quantities of Spent Mushroom Compost (SMC), with the state of

Pennsylvania alone producing approximately 1.1 million tons annually. Before being removed from mushroom production facilities, SMC is typically steam-pasteurised to eliminate pests and pathogens. Although currently used as compost or soil amendment, its direct use for cultivating microgreens is often limited due to suboptimal compatibility with many species. However, blending SMC with other substrates may help reduce elevated levels of soluble salts, potentially making it a viable alternative for microgreen cultivation. SMC typically contains around 25% organic matter, has a neutral or near-neutral pH, and provides a reasonable supply of both macro- and micronutrients. Nevertheless, its salt content in some cases may pose a challenge, requiring careful management before use in sensitive crops like microgreens[19].

3.1.6 Coconut Fibre

Coconut fibre, derived from the mesocarp of *Cocos nucifera L.*, exhibits high water-holding capacity, effective drainage, and aeration, along with a notable cation exchange capacity. It maintains a pH between 5.5 and 7, porosity of 90–95 %, and density around 80–100 kg/m^3. These traits support plant hydration and nutrient availability. Additionally, microgreens grown in coconut fibre showed reduced nitrate accumulation and, in the case of red basil, increased sucrose content, which is important for postharvest shelf life[20].

3.1.7 Vermiculite

Vermiculite, an inorganic silicate mineral, also supports microgreen cultivation due to its high porosity (85–95%), good water retention, and aeration. It typically has a neutral to slightly alkaline pH (7–8), high cation exchange capacity, and density ranging from 80–150 kg/m^3. It promoted higher anthocyanin and phenolic concentrations in red basil, enhancing the nutraceutical value[20].

3.1.8 Jute

Jute, a sustainable organic fibre and by-product of industrial processes, showed potential as a low-cost, biodegradable medium. While detailed technical data on jute are limited, the study reported competitive yield outcomes, particularly for rocket microgreens. Red basil grown on jute also exhibited elevated anthocyanin and phenolic levels, indicating its usefulness in enhancing bioactive compound accumulation[20].

3.1.9 Peat Moss

Peat moss has been traditionally used for microgreen cultivation due to its favourable structure, good water-holding capacity, and ability to retain nutrients. It supports seed germination and early growth effectively. However, environmental concerns arise from its non-renewable nature and the ecological damage associated with its extraction. This has led to the search for sustainable alternatives in commercial and research-based microgreen production[21].

3.1.10 Perlite

Perlite is an inert, volcanic mineral commonly used in combination with other media. It enhances aeration



(a). soil **(b).** Jute **(c).** Hydroponics **(d).** Coconut fibre **(e).** Aeroponics

Figure 1. Different growing media for microgreens.

and drainage in the substrate mixture. Although it does not retain water as effectively as vermiculite, it helps prevent waterlogging and root diseases when blended with moisture-retentive materials. Due to its inert nature, it does not supply nutrients and must be supplemented with nutrient solutions[21].

3.2 Lighting Techniques to Grow Microgreens

Light quality, intensity, and duration are crucial factors influencing the growth, morphology, and phytochemical profile of microgreens. In controlled environments, artificial lighting is widely used to optimise plant productivity and functional quality.

3.2.1 UV-A Light

UV-A light (315–400 nm) is a component of the ultraviolet spectrum that can influence secondary metabolite production in microgreens. In this study, UVA treatment enhanced the biosynthesis of phenolic compounds and flavonoids, particularly in Brassicaceae species. Exposure to UVA stimulated antioxidant enzyme activity and increased levels of health-promoting compounds such as anthocyanins, contributing to improved functional quality. Additionally, UVA exposure positively affected plant morphology, with some microgreen species showing compact growth and vibrant colouration. This suggests that UVA light serves not only as a growth regulator but also as a tool for improving the nutraceutical properties of microgreens[22].

3.2.2 UV-B Radiation

UV-B radiation (280–315 nm) has shown promising results in enhancing the phytochemical content of microgreens, particularly red cabbage. When applied in low doses shortly before harvest, UV-B acts as a mild stressor that stimulates the plant's natural defence mechanisms. This results in an increase in beneficial compounds such as flavonoids, anthocyanins, and other phenolic compounds. These bioactive substances contribute significantly to the antioxidant capacity and nutritional value of the microgreens. Importantly, low-dose UV-B exposure did not cause visual damage or negatively affect the physical appearance of the plants, making it a viable preharvest treatment in controlled environment agriculture[23].

3.2.3 UV-C Radiation

UV-C radiation (100–280 nm), while more energetic and potentially harmful at high intensities, can also be used effectively in very low doses. In the case of red cabbage microgreens, UV-C exposure led to a notable enhancement in the levels of ascorbic acid, anthocyanins, and glucosinolates, all of which are associated with antioxidant and disease-preventing properties. Like UV-B, UV-C serves as an abiotic elicitor, triggering metabolic pathways that promote the synthesis of secondary metabolites. When used carefully, UV-C did not impair plant growth or quality, suggesting its potential as a light treatment method to boost the functional food value of microgreens[23].

3.2.4 LED Light (Blue, Red, White and Red + Blue)

The use of Light-Emitting Diodes (LEDs) allows precise manipulation of spectral quality, with red light supporting stem elongation and photosynthetic efficiency, while blue light enhances chlorophyll content, compact growth, and the accumulation of secondary metabolites like flavonoids. White light, offering a broad spectrum, promotes uniform development and balanced visual traits. Combining red and blue light in specific ratios is found to be especially effective in optimising both growth and nutrient density. Additionally, supplemental use of far-red or ultraviolet (UV) radiation can act as an abiotic stimulus to further boost the production of health-promoting phytochemicals. Therefore, tailored lighting strategies are essential to maximise both yield and functional quality in microgreens cultivation[24].

4. Nutritional Composition of Microgreens

4.1 Macronutrients and Macronutrients

Microgreens offer a concentrated source of macronutrients, including protein, dietary fibre, and beneficial lipids, while generally providing low levels of carbohydrates. For example, research assessing red amaranthus, fenugreek, and spinach microgreens revealed protein contents of approximately 4.5 g per 100 g fresh weight, substantially higher than corresponding mature leaves, alongside modest fat levels and elevated ash and fibre content[25]. Culinary microgreens exhibit

notable variability in their nutritional composition. Protein content ranged between 1.8–4.4 g/100g, with fennel and sunflower microgreens showing the highest levels. Fennel also contained the highest amounts of total dietary fibre (4.28 g/100g) and insoluble dietary fibre (3.98 g/100g), while French basil had the lowest. Soluble Dietary Fibre (SDF), contributing 0.7–16 % of Total Dietary Fibre (TDF), was relatively abundant in roselle and radish[26]. Similarly, a comparative study of radish cultivation confirmed that microgreens contain significantly more soluble dietary fibre compared to sprouts and roots, with protein and fat also enriched in microgreen form[27].

The mineral composition of microgreens varies significantly across species. Potassium was identified as the most abundant macro-element, while iron and zinc were the dominant trace elements. Fennel microgreens showed the highest levels of calcium, potassium, and sodium, indicating their potential as a rich source of these essential nutrients. Spinach microgreens were highest in magnesium, while roselle had the greatest concentrations of phosphorus, zinc, and selenium. On the other hand, carrot microgreens had the lowest Fe content, sunflower the least Zn, and onion microgreens the lowest Se. Spinach and fenugreek also exhibited low levels of multiple elements[26].

On the micronutrient front, a detailed analysis of six different microgreen species (bean, sunflower, pea, broccoli, red beet, black radish) demonstrated remarkable mineral content per 100 g Fresh Weight (FW): Bean microgreens were the richest in phosphorus (4.88 mg/100 g FW) and potassium (416.05 mg/100 g FW), whereas red beet and broccoli microgreens recorded the lowest concentrations of these elements, respectively. Magnesium levels peaked in broccoli microgreens at 86.83 mg/100 g FW, while sunflower microgreens had the lowest at 45.96 mg/100 g FW. In terms of calcium, sunflower microgreens exhibited the highest content (145.29 mg/100 g FW), with red beet microgreens at the lower end (67.18 mg/100 g FW). Broccoli microgreens also stood out for their exceptional levels of iron (2610.42 µg/100 g FW) and manganese (350.56 µg/100 g FW). Additionally, pea microgreens contained the most copper (221.91 µg/100 g FW), while sunflower microgreens had the highest zinc content at 956.34 µg/100 g FW[28].

4.2 Phytochemical and Bioactive Compounds

These young greens are recognised for being densely packed with both macro- and micronutrients, including essential minerals such as iron, zinc, potassium, calcium, nitrogen, phosphorus, sulfur, manganese, selenium, and molybdenum. In addition to their mineral richness, microgreens are abundant in a variety of bioactive phytochemicals known to support health and combat disease. High concentrations of ascorbic acid (vitamin C), phylloquinones (vitamin K), α-tocopherol (vitamin E), β-carotene (provitamin A), phenolic antioxidants, carotenoids, anthocyanins, glucosinolates, and natural sugars have been reported in many microgreen varieties, making them a promising dietary source for enhancing overall nutritional intake and promoting human well-being[29].

Kowitcharoen *et al.*, stated that colour plays a critical role in consumer preference and market value of microgreens, with chlorophyll, carotenoids, and anthocyanins being the key pigments contributing to their visual and nutritional quality. Microgreens generally exhibit higher levels of chlorophyll and carotenoids compared to sprouts. In the present study, total chlorophyll content ranged from 12.35 to 112.62 mg/100g, with green pea having the lowest and lentil microgreens having the highest concentration. Carotenoid levels followed a similar trend, ranging from 4.40 to 28.37 mg/100g, with notably high values in Brassicaceae species such as broccoli, Chinese kale, radish, and red cabbage, aligning with or exceeding earlier reports[30].

The study of Balik *et al.* showed that broccoli microgreens demonstrated the highest total phenolic content at 825.53 mg (Gallic Acid Equivalent) GAE/100 g Fresh Weight (FW), followed by black radish at 659.53 mg GAE/100 g FW. In terms of total flavonoid content, red beet microgreens ranked highest at 1625 mg/100 g FW, with black radish again showing substantial levels at 1193 mg/100 g FW. Microgreens exhibited strong antioxidant activity, as measured by their ability to scavenge DPPH free radicals. Black radish microgreens recorded the highest DPPH radical scavenging capacity at 83.32%, followed by bean, sunflower, red beet, and broccoli. In contrast, pea microgreens showed the lowest antioxidant activity at 70.13%, though still notable in a nutritional context[28].

5. Health Benefits of Consuming Microgreens

Recent studies have begun to investigate the potential of microgreens in modulating chronic conditions such as lung diseases, cancer, and cardiovascular disorders. Emerging evidence highlights that microgreens possess a diverse and rich polyphenol profile, along with potent antioxidant capacity, which may contribute to disease prevention. Their high bioavailability further enhances their appeal as a dietary component, supporting their inclusion in functional nutrition strategies aimed at promoting long-term health[31]. Shallots are rich in bioactive compounds such as vitamin C, allicin, methine, isoalliin, propin, and lipid-soluble sulfur compounds. These constituents are linked to a wide range of health benefits, including anti-cancer, anti-diabetic, antioxidant, anti-hypertensive, anti-depressant, neuroprotective, anti-inflammatory, and antiparasitic effects[32]. Microgreen supplementation has been found effective in reducing body fat, cholesterol, hepatic triglycerides, and inflammatory cytokines. Varieties from the Brassicaceae and Lamiaceae families contain bioactive compounds such as indole-3-carbinol, retinoic acid, and β-carotene metabolites, which play a role in weight regulation by inhibiting adipogenesis, the formation of fat cells[33] (Figure 2).

Microgreens have gained recognition as a potent functional food due to their rich concentration of vitamins, minerals, antioxidants, and bioactive compounds. They offer significantly higher levels of nutrients than their mature plant counterparts, including essential vitamins like A (provitamin carotenoids), C, E (tocopherols), and K1 (phylloquinone). Studies

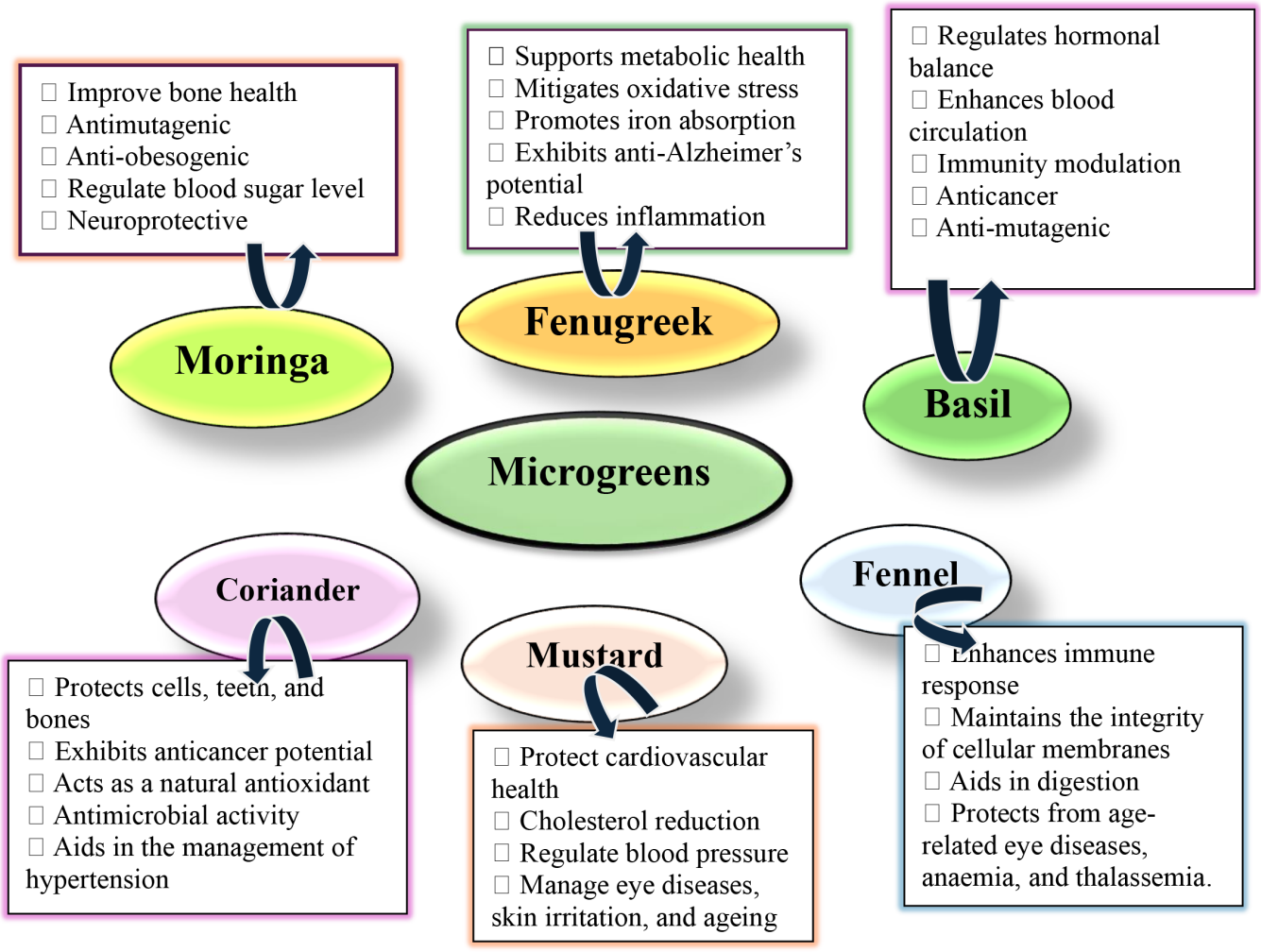


Figure 2. Health-promoting roles of microgreens[48].

show that red cabbage microgreens, for example, can lower the Low-Density Lipoprotein (LDL) cholesterol and inflammatory markers like C-reactive protein and TNF-α, particularly in high-fat diets. Microgreens also demonstrate antimicrobial properties, with kale and red spinach microgreens being more effective than mature greens against specific pathogens. Their potential to regulate the gut microbiome and suppress fat accumulation may help in managing conditions like obesity, cardiovascular diseases, and type 2 diabetes[34].

Inflammation is a key factor in the onset and progression of chronic diseases like obesity, cardiovascular disease, and cancer. Microgreens, particularly those from cruciferous vegetables, are rich in glucosinolates and phenolic compounds such as flavonoids and hydroxycinnamic acid derivatives. These bioactives can modulate inflammatory responses by interfering with pathways like NF-κB, which regulates pro-inflammatory gene expression. Compounds like kaempferol and quercetin, abundant in cruciferous microgreens, also help reduce inflammation by suppressing COX-2, a key pro-inflammatory enzyme. This makes microgreens potent anti-inflammatory dietary components[35].

Cancer remains the second leading cause of death worldwide, with its incidence expected to rise. This highlights the urgent need for affordable, plant-based prevention strategies. Microgreens, rich in polyphenols, vitamins, carotenoids, and minerals, show potential in cancer prevention by influencing metabolic pathways in cancer cells. Particularly, microgreens from the Brassicaceae family are abundant in glucosinolate derivatives, which can activate Phase I and II detoxification enzymes, helping to neutralise carcinogens and enhance cellular defence mechanisms[36]. Diabetes, largely driven by poor lifestyle and diet, is a growing chronic disease influenced by both environmental and genetic factors. While pharmaceutical interventions can help, they may lead to adverse side effects. Hence, the inclusion of low-sugar, plant-based foods is encouraged. Microgreens, particularly broccoli microgreens, have shown promise in reducing type 2 diabetes symptoms by improving gut microbiota, increasing propionic acid levels, and alleviating insulin resistance, positioning them as a potent functional food for diabetes management[37].

6. Safety, Shelf Life, and Post-harvest Handling

6.1 Safety

While microgreens are recognised for their high nutritional value, their short shelf life, lack of standardised cultivation practices, and microbial contamination risks pose significant limitations. Current production is largely unregulated, and hygiene during post-harvest handling is a major concern. Moreover, limited awareness among consumers and higher production costs hinder widespread adoption. Future research should focus on developing cost-effective, hygienic, and scalable cultivation systems, improving shelf stability, and creating regulatory guidelines to ensure food safety and promote market growth[38].

Microgreens, though highly nutritious, pose several safety challenges due to their delicate structure and the humid conditions required for growth, which can promote microbial contamination. Pathogens like *Salmonella*, *Listeria monocytogenes*, and *E. coli* have been associated with leafy greens and may also threaten microgreens, especially when grown hydroponically or in soil substitutes. Contamination may occur via seeds, water, substrates, or handling practices. Thus, strict hygiene during production, disinfection of seeds, clean water use, and Controlled Environment Agriculture (CEA) practices are crucial to ensure food safety in microgreen production[39].

6.2 Shelf Life

Microgreens are highly perishable due to their tender structure and high moisture content, which accelerates respiration and senescence. Their shelf life typically ranges from 3 to 14 days, depending on the species, post-harvest handling, and storage conditions. Deterioration occurs rapidly due to water loss, yellowing, and microbial spoilage, especially under suboptimal conditions. Factors influencing shelf life include harvesting stage, temperature, humidity, packaging material, and sanitary practices during processing. Using Modified Atmosphere Packaging (MAP) and maintaining low storage temperatures (0–5 °C) are effective in prolonging freshness and preserving nutritional quality[40].

The shelf life of microgreens is influenced by a range of biological, environmental, and post-harvest

factors. One key determinant is the species or variety, as different microgreens vary in their structural resilience and moisture content. The type of packaging significantly affects shelf life; materials that allow for proper moisture and gas regulation, such as modified atmosphere packaging, can effectively reduce spoilage. Storage temperature is another critical factor; maintaining a low temperature around 4°C helps slow down respiration and microbial activity. Controlling relative humidity is important, as excessive moisture may promote microbial growth, while too little can cause wilting. Finally, stringent sanitation practices during harvest and processing are essential to extend shelf life and ensure product safety[41].

6.3 Post-harvest Handling

The primary goals of postharvest technology are to maintain quality and minimise losses in fresh produce. One effective approach is passive Modified Atmosphere Packaging (MAP) using materials with high Oxygen Transmission Rates (OTR), such as perforated polyethene films. Studies have shown that polyethene bags preserve postharvest quality better than polypropylene, particularly for microgreens like radish and Chinese cabbage. Additionally, sunflower microgreens demonstrated longer shelf life and better nutritional retention in polystyrene trays compared to Low-Density Polyethene (LDPE) bags. Despite widespread use of plastic clamshells commercially, comparative scientific evaluations with polyethene packaging are lacking and require further investigation[42].

Broccoli microgreens, though rich in bioactive compounds, face limited marketability due to their high metabolic rate and short shelf life. A study demonstrated that postharvest treatment using a combination of ascorbic acid and citric acid, stored under modified atmospheric conditions (15% CO_2 and 5% O_2), significantly enhanced their postharvest quality. This approach improved the retention of flavonoids, phenolics, chlorophyll, and antioxidant activity, while preserving firmness and reducing weight loss. The treatment also maintained visual quality and consumer acceptability, effectively extending shelf life to 12 days[43].

Preharvest treatment with calcium chloride ($CaCl_2$) has proven beneficial in preserving key bioactive compounds and extending the shelf life of broccoli microgreens. Specifically, a 10 mM $CaCl_2$ application effectively maintained levels of glucoerucin and total aliphatic glucosinolates. In addition, light treatment during storage has emerged as a valuable strategy to delay senescence. Studies on radish microgreens have shown that light exposure helps increase ascorbic acid content while maintaining α-tocopherol and total phenolic levels, thereby enhancing overall antioxidant capacity. Similar outcomes have been reported in pakchoi, where light irradiation preserved postharvest quality effectively[44].

7. Market Potential and Consumer Acceptance

7.1 Consumer Acceptance

Modern consumers are increasingly drawn to innovative food products that not only promote health and longevity but also offer a satisfying culinary experience. As key drivers of food industry trends, consumer acceptance plays a critical role in the success of novel foods. Factors such as knowledge, attitude, belief, innovation, and perception significantly influence food acceptability. Consumer perception and acceptance of microgreens were assessed through an online survey and sensory evaluation. While challenges such as limited awareness, high perishability, and cost were noted, consumers expressed a strong positive attitude towards microgreens, particularly for their health benefits. Sensory evaluations showed that beetroot and carrot microgreens were especially well-received in terms of taste and overall liking[45].

7.2 Economic Feasibility

As an emerging agricultural commodity, microgreens offer significant potential for promoting agricultural diversification, economic development, and human health, while also supporting environmental sustainability. The global market for microgreens is expanding rapidly, with forecasts indicating a Compound Annual Growth Rate (CAGR) of 12–20% in the near future[46]. Due to their high market value per unit area, microgreens often yield greater revenue than conventional crops. Their popularity in gourmet restaurants and speciality food markets further enhances profitability. Additionally, their short growth

cycle allows for frequent harvests, making them a financially viable option for producers[47].

7.3 Microgreens in Foods

The growing consumer demand for microgreens is largely driven by their health-promoting properties and their versatility in culinary applications. Widely used by chefs around the world, microgreens enhance dishes not only with their nutritional value but also through their distinctive flavours, ranging from spicy to sweet and vibrant colours, which elevate a dish's visual appeal. They are commonly incorporated into salads, soups, and sandwiches and are frequently used as garnishes for pizzas, curries, omelettes, and various other cuisines[33].

Microgreens are available in a wide range of flavours, colours (such as red, purple, green, and yellow), textures, and appearances, making them visually and sensorially appealing. Beyond culinary applications, they are also utilised in the beverage industry, particularly in juices and fermented drinks. Broccoli sprouts are considered functional foods due to their high content of glucoraphanin, a precursor to sulforaphane, a compound known for its anticancer properties[37].

8. Culinary Uses of Microgreens

Unlocking the nutritional and functional value of microgreens demands further research on their micronutrient, vitamin, and phytochemical profiles to better understand their health benefits. Studies should also explore the antioxidant mechanisms involved in managing oxidative stress-related diseases. Optimising cultivation techniques, including light conditions and growing media, can improve their nutritional and sensory qualities. Since microgreens have a short shelf life, advanced postharvest handling and packaging methods are essential. Additionally, ensuring food safety and exploring consumer acceptance and culinary uses will support their integration into healthy diets[38]. Mechanical handling processes such as washing, spinning, and drying often cause physical damage to microgreens, leading to reduced shelf life. Addressing these challenges requires the development of appropriate strategies. As the demand for industrial-scale microgreen production and ready-to-eat packaging grows, effective sanitation becomes increasingly critical. Further studies are essential to evaluate the efficacy of different sanitising agents and drying techniques, especially considering the urgent need for safe and efficient alternatives to sodium hypochlorite that maintain product quality and prolong freshness[48].

9. Conclusion

Microgreens represent a convergence of nutritional excellence, agricultural sustainability, and culinary versatility. Their rich nutrient and phytochemical profiles offer compelling evidence for their inclusion in therapeutic nutrition and functional food systems. With demonstrated benefits in mitigating oxidative stress, inflammation, and metabolic disorders, microgreens hold promise as preventative agents against chronic diseases. However, realising their full potential requires overcoming barriers related to short shelf life, food safety, and consumer awareness. Continued research into optimised growth conditions, innovative postharvest technologies, and effective sanitisation methods is critical. Furthermore, expanding consumer education and market accessibility can accelerate the integration of microgreens into mainstream diets, thereby contributing to global health promotion and sustainable agriculture. Future research on microgreen supplementation is essential to evaluate their effectiveness in the prevention and management of non-communicable diseases.

10. References

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Author Contribution

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