# Microgreens: nutritional properties, health benefits, production techniques, and food safety risks (#89455)



First submission

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3. **VALIDITY OF THE FINDINGS**
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### BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Is the review of broad and cross-disciplinary interest and within the scope of the journal?
- Has the field been reviewed recently? If so, is there a good reason for this review (different point of view, accessible to a different audience, etc.)?
- Does the Introduction adequately introduce the subject and make it clear who the audience is/what the motivation is?

### STUDY DESIGN

- Article content is within the Aims and Scope of the journal.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.
- Is the Survey Methodology consistent with a comprehensive, unbiased coverage of the subject? If not, what is missing?
- Are sources adequately cited? Quoted or paraphrased as appropriate?
- Is the review organized logically into coherent paragraphs/subsections?

### VALIDITY OF THE FINDINGS

- Impact and novelty not assessed. Meaningful replication encouraged where rationale & benefit to literature is clearly stated.
- Conclusions are well stated, linked to original research question & limited to
- Is there a well developed and supported argument that meets the goals set out in the Introduction?
- Does the Conclusion identify unresolved questions / gaps / future directions?

supporting results.



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*improved upon before Acceptance.*

# Microgreens: nutritional properties, health benefits, production techniques, and food safety risks

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“Microgreens” is a hypothetical name given to a new class of edible plants that have become popular in recent years. Microgreens are plants that are larger than sprouts and smaller than baby greens, with an average height of 2-8 cm. They have some advantages, such as the dense and digestible nutrient profile they contain, appeal to vegan and vegetarian individuals, and simple cultivation in a home environment. For microgreens to have a superior nutrient profile, industrial cultivation techniques have been developed under different environmental conditions. Also, the current health benefits of microgreens are noteworthy. On the other hand, they may contain some important food safety risks, especially due to cross-contamination. In this study, a detailed literature review about microgreens, which have become a trend in the last 10 years, was conducted, and the available information was compiled.

# Microgreens: nutritional properties, health benefits, production techniques, and food safety risks

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## Abstract

"Microgreens" is a hypothetical name given to a new class of edible plants that have become popular in recent years. Microgreens are plants that are larger than sprouts and smaller than baby greens, with an average height of 2-8 cm. They have some advantages, such as the dense and digestible nutrient profile they contain, appeal to vegan and vegetarian individuals, and simple cultivation in a home environment. For microgreens to have a superior nutrient profile, industrial cultivation techniques have been developed under different environmental conditions. Also, the current health benefits of microgreens are noteworthy. On the other hand, they may contain some ~~important~~ food safety risks, especially due to cross-contamination. In this study, a detailed literature review about microgreens, which have become a trend in the last 10 years, was conducted, and the available information was compiled.

**Keywords**: Hydroponic production, microgreens, super nutrients

## Introduction

Food systems cover food production processes, which also include packaging, transportation, and storage. On the other hand, a substantial portion of the food produced in the global food chain is subject to deterioration during transportation or storage, and this huge food waste threatens food security globally (Weber, 2017). In addition, the need for the production of nutritious food has increased due to malnutrition, which approximately 800 million people worldwideface, and the nutritional problems of the rapidly increasing global population. Existing data show that 60%, 30%, and 15% of the world's population have micronutrient deficiencies of Fe, Zn, and Se, respectively, which is one of the most common nutritional problems in both developed and developing countries (Frąszczak and Kleiber, 2022; Bhaswant et al., 2023). Modern agricultural practices have significant disadvantages in terms of environmental damage, considering the irrigation water and pesticides used. Food production methods that minimize environmental impacts should be prioritized to ensure sustainable nutrition and protect the ecosystem (Weber, 2017).

Microgreens are a new class of edible plants that are gaining popularity today (Mir, Shah, & Mir, 2017). Lifestyle changes, increasing concerns about health, the orientation toward healthy nutrition and functional foods, as well as the decrease in agricultural lands, and the disadvantages of modern agricultural practices have led to an increased interest in microgreens. Microgreens, which have many advantages in terms of nutritional properties, have not been associated with any disease according to the current literature (Teng et al., 2021; Sharma et al., 2022; Teng et al., 2023). With a pleasing color, texture, and flavor, sprouts and microgreens are potentially therapeutic and functional foods. They have many positive features such as having a short growth cycle (14 days on average depending on the species) and growing hydroponically (Mir, Shah, and Mir, 2017; Moraru, Rusu, and Mintas, 2022; Sharma et al., 2022; Allogia et al., 2023). Sprouts and microgreens can be grown in a wide variety of areas, from home balconies and gardens to large farms, do not require professional care, and can be grown by anyone (Bhaswant et al., 2023; Teng et al., 2023). It is predicted that microgreens may also contribute to astronauts' feeding in the future and may benefit the physical and psychological health of the crew during long space flights (Parasido et al., 2018; Teng et al., 2023).

Microgreens have a good potential to improve and diversify human nutrition with their phytochemical properties (Ebert, 2022). Moreover, unlike baby and mature plants, sprouts and microgreens do not require additional effort and cost such as large land, soil, fertilization, extra labor, or professional care and can be produced quite simply and quickly (Bhaswant et al., 2023). In addition, microgreens are very suitable food, especially for vegan and vegetarian individuals, and can easily adapt to city life (Parasido et al., 2018). Therefore, they have the potential to solve the malnutrition problem (Pathan and Siddiqui, 2022).

Microgreens grow through the germination of seeds in the dark and under high relative humidity. It was reported that the consumption of seeds in the form of sprouts and microgreens dated back to the ancient Egyptians, around 3000 BC (Ebert, 2022). The sprouts are harvested and consumed when the cotyledons are still under-developed and the true leaves are immature, usually in less than a week (3-5 days) when appropriate conditions are provided. The whole sprout-*seeds, roots, and shoots*-is consumed. On the other hand, microgreens are slightly larger than sprouts (average 2-8 cm tall), smaller than baby and mature plants, and are harvested within 10-12 days with the development of cotyledons under a light environment. The stem, cotyledons, and the first true leaves are consumed (Ebert, 2022; Bhaswant et al., 2023).

Microgreens are often used as garnishes in salads, soups, sandwiches, pizzas, pancakes, and appetizers (Mir, Shah, & Mir, 2017; Ebert, 2022). They can also be consumed with healthy smoothies, juices, and other beverages (Gupta et al., 2023).

In this review, current literature on the main sources and nutritional properties of microgreens, their health benefits, production techniques, and food safety risks was investigated. Microgreens, which is an alternative food for all individuals aiming to eat healthy and those who prefer to eat vegan, vegetarian and similar diets, are also phytochemically advantageous compared to mature greens. In addition, when the necessary production conditions are provided, it can become nutraceutical for people with special needs. Therefore, this study is necessary because it reveals the potential and health advantages of microgreens, which has become one of the popular disciplines of recent years, to be a solution to the search for alternative food and nutritional deficiencies all over the world.

## Survey Methodology

Microgreens is a new discipline that has been popular in recent years, and the available literature is quite limited. All relevant studies on the production techniques, health benefits, nutritional properties and food safety risks of Microgreens are summarized in this review. To identify articles related to microgreens, we conducted searches on the Science Direct, Scopus, PubMed Web of Science and Google Schoolar databases using the keyword 'microgreens'. After passing the abstract screening, the full text of the found publications was downloaded. Studies not related to the subject were excluded and only full-text articles were used for data extraction and analysis.

## Nutritional properties of microgreens

Microgreens can be produced from the seeds of a wide variety of plants, such as legumes (i.e., chickpeas, lentils, soybeans, mung beans, and black-eyed peas), grains (i.e., barley, rye, corn, oats, and rice), pseudo cereals (i.e., quinoa and buckwheat), oilseeds (i.e., sunflower seeds, hazelnuts, flax seeds, sesame, and almonds), and vegetables (i.e., beetroot, radish, arugula, cress, fenugreek, basil, spinach, onion, leek, celery, lettuce, mustard, cabbage, and broccoli) (Ebert, 2022). In addition, although it is not used frequently, microgreens can be produced from many wild species. Due to their phytochemical richness, species belonging to the *Brassicaceae* family are more preferred and come to the fore (Renna et al., 2018).

Microgreens have become common with their nutritional advantages and health benefits in in-vivo and in-vitro studies conducted in recent years (Ebert, 2022). They are also called 'super nutrients' since they are very rich in antioxidants, vitamins, minerals, glucosinolates, chlorophyll, phylloquinone, and flavonoids and anthocyanins, which are two phenolic compounds (Kyriacou et al., 2022; Alloggia et al., 2023). Microgreens are rich in minerals, such as Fe, Zn, K, Ca, N, P, S, Mn, Se, and Mo (Bhaswant et al., 2023). They also contain plenty of α-tocopherol, beta carotene, ascorbic acid, and phylloquinone (vitamin K1). *Brassicaceae* microgreens are also reported to be a good source of K, Ca, Fe, and Zn in general (Paradiso et al., 2018). In a recent study, Marchioni et al. (2021) examined some species of the *Brassicaceae* family (broccoli, radish, mustard, arugula, and watercress) comparatively on the basis of some phytochemical compounds, such as chlorophylls, polyphenols, carotenoids, anthocyanins, ascorbic acid, total reducing sugar, and antioxidant activity. In the study, broccoli was found to have the highest nutrient profile and good antioxidant capacity with the highest polyphenol carotenoid and chlorophyll content, while mustard was characterized by its high ascorbic acid and total sugar content. Arugula was reported to have the lowest antioxidant content.

Sprouts and microgreens are more digestible than seeds (Kyriacou et al., 2022). During the germination process of the seed, hydrolytic enzymes are activated. They increase the bioavailability of the product by separating the nutrients from the phytate chelates. The bioavailability of particularly Fe and Ca and the digestibility of proteins increase as a result of germination and microgreen growth and the inactivation of phytate, oxalate, and tannins. Ascorbic acid, tocopherol, beta carotene, and phylloquinone levels increase in microgreens via photosynthesis (Ebert, 2022).

Many studies have proven that microgreens have a better nutrient profile than mature plants. For example, Ayeni (2021) compared the nutrient content of microgreens/baby leaves of tropical spinach (*Amaranthus sp.*) and roselle plant (*Hibiscus sabdariffa L.*) with mature leaves. Compared to mature leaves grown in the field, greenhouse-grown micro/baby greens were found to be richer in digestible proteins, P, K, Mg, Fe, Mn, and Zn, although poorer in digestible carbohydrates and Ca. Weber (2017) reported that broccoli microgreens contained more Mg, Mn, Cu, and Zn than mature plants. Microgreens are known to have four to 40 times higher concentrations of carotenoids than mature plants (Frąszczak and Kleiber, 2022). It has been reported that the Ca, Mg, Fe, Mn, Zn, Se, and Mo contents of lettuce microgreens are higher than those of mature plants (Paradiso et al., 2018). Zou et al. (2021) comparatively investigated nutritional metabolites in Chinese cabbage (*Brassica rapa subsp. chinensis var. Parachinensis*) during the growth process from shoot to mature leaves. In the study, while essential amino acids, folate, and β-cryptoxanthin decreased from sprouts to mature leaves, the total amount of reducing sugar, carotenoids, and vitamin K1 increased. It was also reported that most of the important minerals were concentrated in microgreens. Microgreens have a higher nutritional value compared to mature plants, which is associated with the fact that these nutrients are more intense nutrient sources (Weber, 2017). Compared to the nutrient concentration in mature leaves, the leaves of microgreens were found to have a higher nutrient content (Xiao et al., 2012).

The raw consumption of microgreens and not exposing them to heat treatment prevents losses in heat-sensitive vitamins such as ascorbic acid. Similarly, the ratio of chlorophyll and phenolic compounds with antioxidant activity is higher in microgreens compared to sprouts (Ebert, 2022). Microgreens are also characterized by high absorption of these bioactive compounds (Frąszczak and Kleiber, 2022). El-Nakhel et al. (2020) comparatively investigated the phytochemical and antioxidant properties of green and red-pigmented lettuce (*Lactuca sativa L. var. capitata cultivars*) at different developmental stages. In the study, Ca and Mg were found to be more intense in microgreens than mature leaves, regardless of cultivar. Total polyphenols were higher in microgreens, especially in the red-pigmented lettuce cultivar. In addition, it was reported that this density increased in red-pigmented lettuce with higher levels of P, K, nitrate, chlorophyll, lutein, and beta-carotene in mature leaves.

Biological enrichment processes applied to foods can also be applied to microgreens. Biofortification is a sustainable approach that increases the bioavailability for humans by improving the nutritional quality of plants and has the potential to offer long-term solutions to minimize conditions such as food insecurity and malnutrition (Ma et al., 2022). Frąszczak and Kleiber (2022) studied the effect of the iron chelate-fortified solution on plant growth and mineral concentrations of some microgreens (purple kohlrabi, radish, peas, and spinach). In the study, it was reported that Fe content increased in the leaves of all species except radish, but this increase reduced the ratio of zinc and copper regardless of genotype. Puccinelli et al (2019) reported that when microgreens produced from basil seeds enriched with selenium were included in human nutrition, they could support general immunity by contributing to the antioxidant defense system. Newman et al. (2022) reported that the total phenol content and antioxidant capacity could be increased by enriching basil, coriander, and green onion microgreens with selenium. Kathi et al. (2023) fed broccoli microgreens grown hydroponically on polyethylene pads with different concentrations of ascorbic acid solutions (0% (control), 0.05%, 0.1%, 0.25%, and 0.5%) and examined the effect of the treatment on nutrient composition. In the study, it was reported that ascorbic acid solution increased biomass, carotenoids, chlorophyll amount, potassium levels, especially ascorbic acid in microgreens, but that this increase in ascorbic acid showed a negative correlation with minerals N, P, Mg, Ca, and S. Therefore, further studies are needed for the optimization of genotype-specific nutrient enrichment processes.

In addition to their highly valuable nutritional compositions, microgreens also meet consumer demands in terms of their good organoleptic properties, such as sensory intense taste, lively texture, pleasant aroma, and beautiful appearance. Depending on the variety, their taste can be bitter, sour, mild, or spicy (Bhaswant et al., 2023). Michell et al. (2020) presented six types of microgreens (arugula, broccoli, bull beet, red cabbage, red garnet amaranth, and pea sprouts) to the sensory perception of the consumer and examined their acceptability in a consumer panel of 99 individuals. In the study, it was reported that all species received high average ratings of appreciation from the participants.

## Health benefits of microgreens

Antimicrobial, anti-inflammatory, antioxidant, and anticarcinogenic effects of microgreens have been reported (Gupta et al., 2023). Microgreens containing plenty of anthocyanins can alleviate chronic low-grade inflammation, especially due to obesity (Lee et al., 2017). In addition, studies on rats have shown that they are highly effective in improving Diabetes Mellitus (DM) symptoms and increasing insulin sensitivity, reducing body weight, and modulating intestinal microbiota and lipid metabolism (Huang et al., 2016; Li et al., 2021; Mohamed et al., 2021; Khattab et al., 2022; Ma et al., 2022)

Mohamed et al. (2021) investigated the therapeutic effects of barley microgreens added to the diet in streptozotocin-induced diabetic rats with and without aflatoxin. In the study, streptozotocin injection and/or aflatoxin administration significantly increased glucose levels, decreased insulin secretion and beta cell functions, increased oxidative stress, and caused deterioration in liver and kidney functions. The addition of barley microgreens to the diet, independent of streptozotocin, improved all these parameters. In another study, Li et al. (2021) reported that broccoli microgreen juice given to high-fat diet-induced obese C57BL/6J mice for 10 weeks promoted body weight loss by increasing insulin sensitivity and modulating intestinal microbiota. In the study, it was reported that broccoli microgreen juice significantly increased the relative abundance of *Bacteroidetes* in the microbiota composition and decreased the ratio of *Firmicutes* to *Bacteroidetes*, which, in turn, contributed to the production of short-chain fatty acids (SCFA), which are known to have anti-inflammatory effects, in the intestines. Ma et al (2022) investigated the effect of lyophilized broccoli microgreens on microbiota, blood lipids, inflammatory factors, and hypoglycemia in rats. In the eighteen-week study, body weight, glucose homeostasis, blood lipid parameters, antioxidant indices, and inflammatory biomarkers improvedand intestinal microbiota composition developed positively following the consumption of broccoli microgreens. The authors noted that microgreens might specifically improve symptoms of Type 2 DM. Similarly, in another eight-week study, it was reported that red cabbage microgreens increased body weight, and decreased LDL levels, triglyceride, and cholesterol levels in rats (n:60, male) given a high-fat diet (Huang et al., 2016). These results suggest that microgreens can reduce body weight gain, regulate cholesterol metabolism, and thus be protective against cardiovascular disease risks. In addition, Khattab et al. (2022) reported that powdered and pelleted barley (Hordeum vulgare L.) microgreens reduced reproductive dysfunction and oxidative stress in streptozotocin-induced diabetes and aflatoxicosis in male mice.

Microgreens are also considered a nutraceutical factor. Renna et al. (2018) reported that low K-containing microgreens could be produced for patients with renal dysfunction. In the study, chicory (*Molfetta*) and lettuce (*Bionda da taglio*) microgreens were grown hydroponically on polyethylene pads with phytonutrient solutions containing K at various concentrations. Regardless of genotype, microgreens grown with nutrient solutions containing less K successfully contained less K and more nutrient-dense value. The authors reported that the production of low-K microgreens could be a therapeutic strategy in individuals with kidney damage.

On the other hand, although quite limited, some studies have been conducted to investigate the effectiveness of microgreens in cancerous cells. Fuente et al. (2020) evaluated the antiproliferative effect of four hydroponically grown *Brassicaceae* family microgreens (broccoli, cabbage, mustard, and radish) between normal and colon cancer cells in vitro. While microgreens did not show any effect in normal cells, they showed an antiproliferative effect in cancerous cells. Therefore, daily consumption of microgreens with a balanced diet may be a preventive nutritional strategy to reduce the burden of chronic degenerative diseases such as colon cancer.

No side effects of microgreens have been reported in studies to date. In a study on this subject, the oral acute (14 days) and subacute (28 days) toxicity of ethanol extract of *Brassica carinata A. Braun* microgreens, which are a type of Ethiopian mustard, was investigated in Wistar rats. In both acute and subacute toxicity studies, no death, signs of abnormality, or intervention-related adverse events were observed at doses of 2000 mg/kg, 1000 mg/kg, 500 mg/kg, and 250 mg/kg. The liver, kidney, lungs, and heart were normal when they were examinedhistopathologically. In the study, it was reported that the extract was safe and non-toxic and that it was used in various regions of Sub-Saharan Africa for gastrointestinal disorders (Nakakaawa et al., 2023).

## Production techniques of microgreens

Today, microgreens can be grown in simple ways at home and in various environmental conditions in the food industry (Bhaswant et al., 2023). Fluorescent tubes or high-pressure sodium lamps are frequently used artificial lighting systems, especially in indoor farming systems. However, in recent years, light-emitting diodes (Light Emitting Diode-LED) have been used more widely due to their advantages such as energy saving, minimum heat transfer to the seed, and durability (Alloggia et al., 2023). In addition, with the development of LED technology, optimization of spectral quality (wavelength), intensity (photon flux), and photoperiod, which can increase the phytochemical content of sprouts and microgreens, have become possible (Kyriacou et al., 2022). Lighting with various wavelengths from the light spectrum (from ultraviolet (UV) to infrared) can affect the biosynthesis of phytochemicals in different ways. (Artés-Hernández et al., 2022). Wavelength is very important to stimulating secondary metabolites by modulating the expression of specific genes (Appolloni et al., 2022). Plants are exposed to abiotic (UV, light, flood, drought, salinity, heavy metals, extreme heat, injuries, etc.) and biotic (bacteria, fungi, insects, and other small animals) stress factors during their growth stages. Under the influence of these stress factors, the transcriptional factors that form the plant's defense mechanism against stress are triggered (Artés-Hernández et al., 2022).

Polyphenols called 'secondary metabolites' produced by plants against stress factors have subgroups, such as phenolic acids, flavonoids, and anthocyanins. These compounds exhibit antioxidant and anti-inflammatory properties as well as free radical scavenging or antimicrobial activities (Appolloni et al., 2022).

Changes in phytochemical compounds can be observed according to the type of UV to which plants are exposed (Appolloni et al., 2022). Brazaitytė et al. (2019) studied the optimum growth and phytochemical content of mustard microgreens (*Brassica juncea L. cv.*) by growing them under UV-A light emitting LEDs of different wavelengths (366 nm, 390 nm, 402 nm) and photoperiods (10 and 16 hours). In the study, the most positive effect on mineral deposition in general, except for Fe, was observed at longer UV-A wavelengths (390 nm, 402 nm) in the 16-hour photoperiod. It was noted that lutein/zeaxanthin and β-carotene content increased in response to the shortest UV-A wavelength (366 nm) in the 10-hour photoperiod and a longer UV-A wavelength (390 nm) in the 16-hour photoperiod. On the other hand, Lu et al. (2021) studied the effect of preharvest UV-B treatment on glucosinolate levels in broccoli microgreens (*Brassica oleracea var. Italica*) grown on a hydroponic pad. In the study, it was reported that the shelf life of broccoli microgreens that had been applied pre-harvest UV-B and calcium chloride spray could extend up to 21 days, there was no significant change in glucosinolate levels in this process, and that the general nutritional quality was preserved. On the other hand, when preharvest UV-B and postharvest UV-B interventions were compared, it was stated that preharvest intervention significantly increased glucosinolate biosynthesis genes and decreased the expression of myrosinase, a gene responsible for the degradation of glucosinolate.

Light conditions are of strategic interest in terms of the phytochemical composition of microgreens (Kyriacou et al., 2022). Many studies have been conducted to examine the effects of infrared, red, blue, and ultraviolet rays on the ontogeny and chemical composition of plants. It has been reported that blue light, especially at 400-500 nm, makes photosynthesis efficient while making the plant shorter, thicker and darker green (Artés-Hernández et al., 2022). In addition, it has been reported that in some genotypes, blue light can increase the production of phenolic acids, flavonoids, carotenoids, anthocyanins, anthocyanidins and some vitamins (E and C) (Appolloni et al., 2022; Artés-Hernández et al., 2022). Liu et al (2022) comparatively investigated the growth, nutritional quality, and antioxidant properties of two microgreens of the *Brassicaceae* family (*Brassica oleracea L.*/cabbage and *Brassica alboglabra bailey*/Chinese kale) under different light conditions. The light conditions included red:blue:green light emitting

LEDs (1:1:1), 30, 50, 70, and 90 μmol $m^{-2}$ $s^{-1}$ PPFD values (Photosynthetic Photon Flux Density/PPFD), and 12, 14, 16, 18, 20-hour photoperiods. In the study, it was reported that the hypocotyl length was shortened in both species with the increase in light intensity and that the chlorophyll, carotenoid, soluble sugar, soluble protein, ascorbic acid, and antioxidant capacity of cabbage microgreens increased in the 14-hour photoperiod at 90 μmol $m^{-2}$ $s^{-1}$ PPFD. These optimum data were observed in Chinese kale microgreens at a PPFD of 70 μmol $m^{-2}$ $s^{-1}$ in a 16-hour photoperiod. Yet, little is known about the effects of different LED light wavelengths and intensities or photoperiods on the growth and nutritional quality of *Brassicaceae* microgreens. In another similar study, Gao et al (2021) examined the growth and nutritional quality of broccoli microgreens under red:blue:green light emitting LEDs (1:1:1) at 30, 50, 70, and 90 μmol $m^{-2}$ $s^{-1}$ PPFD. In the study, it was reported that the most suitable light intensity for the production of broccoli microgreens was 50 μmol $m^{-2}$ $s^{-1}$ PPFD but that the best level of phytochemical accumulation occurred at 70 μmol $m^{-2}$ $s^{-1}$ PPFD. On the other hand, glucosinolates decreased significantly as the light intensity increased from 30 μmol $m^{-2}$ $s^{-1}$ to 50 μmol $m^{-2}$ $s^{-1}$, while it increased significantly as the intensity of the light increased from 50 μmol $m^{-2}$ $s^{-1}$ to 90 μmol $m^{-2}$ $s^{-1}$. Therefore, to produce microgreens of the best nutritional quality, more studies are needed for the optimization of light conditions, which have quite complex effects, according to different plants. In addition, there are studies conducted to test different wavelengths. Samuolienė et al. (2019) grew microgreens of the *Brassicaceae* family (kohlrabi, broccoli, and mizuna) in different light spectral qualities (yellow-orange), in a 16-hour photoperiod, and at 300 μmol $m^{-2}$ $s^{-1}$ PPFD and examined the levels of insoluble sugar (hexose and sucrose), ascorbic acid, beta carotene, non-heme iron, magnesium, and calcium. In the study, the soluble carbohydrate content of mizuna and broccoli microgreens increased significantly under yellow light at 595 nm, while Fe, Mg, and Ca increased significantly in all microgreens at 622 nm in orange light. The authors reported that the accumulation of Fe in microgreens was highly dependent on promoters and inhibitors of Fe and that they associated positive correlations of Fe-Ca and Fe-Mg in kohlrabi and broccoli microgreens and negative correlation of Fe-beta carotene and Fe-soluble carbohydrates in kohlrabi microgreens with this.

In addition to light, factors such as substrate, temperature, humidity, and seed genotype can also affect the nutritional quality, sensory properties, storage, and shelf life of microgreens (Kyriacou et al., 2022; Gupta et al., 2023). Plants need a substrate that will provide them with attachment, water, oxygen, and nutrients while sprouting. Although this substrate is the soil in traditional agriculture, industrial by-products such as perlite, vermiculture, polyethylene foam, compost, rock wool, coconut fiber, sugar cane fiber, and other various substrate alternatives have been developed with the advancement of technology. In addition to all these, biopolymer-growing fibers are widely used in the production of microgreens (Gupta et al., 2023).

Studies into the effect of substrates on the nutritional value of microgreens are very limited (Alloggia et al., 2023). Saleh et al. (2022) studied the growth and biochemical compositions of kale (*Brassica oleracea L. var. acephala*), chard (*Beta vulgaris var. cicla*), arugula (*Eruca vesicaria ssp. sativa*), and Chinese kale (*Brassica rapa var. chinensis*) grown under different substrate conditions. In the study, it was reported that the most productive substrate, in general, was the one containing mostly mushroom compost (30% vermicast + 20% sawdust + 20% perlite + 30% mushroom compost). In another study, Kyriacou et al. (2020) studied the effect of natural fiber substrates (agave fiber, coconut fiber, and peat moss) on the nutritional values and phytochemical composition of coriander, kohlrabi, and Chinese kale microgreens compared to synthetic substrates (capillary mat and cellulose sponge). In the study, it was reported that peat moss improved phytochemical composition without sacrificing product performance compared to other substrates and that natural fiber substrates increased macro-micronutrient concentrations in microgreens compared to synthetic substrates. In another study, broccoli microgreens were grown using different growing methods, and their nutritional values were examined. In the study, it was stated that microgreens grown in vermiculture compost contained more minerals than microgreens grown hydroponically (Weber, 2017).

Some studies have shown that geographic location can also change nutritional quality parameters in microgreens. Priti et al. (2021) compared the microgreens of mung beans and lentils grown at low and high altitudes in terms of ascorbic acid, tocopherol, carotenoids, flavonoid, total phenolics, peroxide activity, proteins, enzymes (peroxidase and catalase), and micro and macronutrient contents. Most of the parameters studied at high altitudes in the study, which were observed to have higher temperature amplitude, more photosynthetic active radiation, and UV-B, were superior.

Optimum nutrient content can be achieved in microgreens with appropriate genotype-specific light intensity, wavelength, and photoperiod (Liu et al., 2022). Today, many studies have focused on optimizing species-specific light parameters for the best nutritional quality in microgreens (Alloggia et al., 2023). According to the available literature, the responses and mechanisms of microgreen genotypes to light conditions are not fully known. However, coincidental similarities in the reported results allow us to make some inferences (Artés-Hernández et al., 2022).

Some procedures that can be applied to microgreens before and after harvest can also increase their nutritional and functional values (Frąszczak and Kleiber, 2022). Sun et al. (2015) reported that preharvest application of calcium chloride (CaCl2) to broccoli microgreens was associated with a higher glucosinolate level. In addition, microgreens have a very short shelf life (Mir, Shah, & Mir, 2017). Paradiso et al. (2018) examined the shelf life of microgreens packaged using the modified atmosphere packaging method and reported that freshly cut microgreens had an average shelf life of 10 days at 5°C. In addition, with the developing technology, some ergonomic and environmentally friendly new packaging techniques can preserve the nutritional quality of microgreens and extend their shelf life (Ghoora and Srividya, 2020).

## Current food safety risks in microgreens

Many environmental factors such as soil, irrigation water, seed storage conditions in microgreens that are generally consumed raw can cause contamination with highly dangerous pathogens, such as Escherichia coli, Salmonella spp., and Listeriaceae, through cross-contaminations (Wright and Holden, 2018; Bergšpica et al., 2020). Especially in plants grown hydroponically, it is usual for viruses present in the feed water to pass into plant tissues. Therefore, post-harvest washing or sanitation applications may be inadequate microbiologically (Reed et al. 2018; Fuzawa et al., 2021).

Reed et al. (2018) investigated the extent to which alfalfa sprouts and Swiss chard microgreens grown from seeds contaminated with two Salmonella enterica serotypes (Hartford and Cubana) are affected by various external factors such as seed storage time and growth environment. They reported that irrigation water and seed storage time had significant effects on the development of Salmonella enterica serotypes in sprouts and microgreens.

Naushad et al. (2022) reported that Listeria monocytogene strains were isolated from some microgreen samples grown in Canada. Xiao et al. (2015) studied E. coli populations in edible and inedible parts and substrates by hydroponically growing white radish seeds (*Raphanus sativus var. Longipinnatus*) contaminated with E. coli in peat moss (also known as peat) and polyethylene pads. It was observed that E. coli significantly survived and multiplied in various tissues of the plant in both types of cultivation, with higher levels in the hydroponic medium. Xiao et al. (2014) investigated the contamination status of sprouts and microgreens grown from white radish seeds contaminated with E. coli. Bacterial growth was reported in both sprouts and microgreens, but significantly less in microgreens, in the study. Wang and Kniel (2015) examined the ability of the virus to attach to the edible tissues of microgreens by contaminating hydroponically grown cabbage and mustard seeds with murine norovirus. In the study, they reported that the virus could hold on to both roots and edible plant tissues and maintain its stability for 12 hours after harvest, gradually decreasing on the 8th and 12th harvest days.

In light of these studies, it is seen that any microbial contamination caused by environmental factors during the entire production process in microgreens can cause serious health problems. This situation creates the need for appropriate sanitation, especially for hydroponically grown microgreens.

## Conclusions

Globally changing nutritional behaviors and trends, food insecurity, malnutrition problems, and above all, climate change and the disadvantages of modern agriculture increase the need for healthy alternative foods. In this context, microgreens have entered the literature as 'super nutrients', which anyone can grow without the burdens of professional equipment, large fields, or chemical fertilization, have a very intense nutrient content and short growth cycle compared to mature plants, and are becoming more and more popular. Very few animal experiments and cell culture studies point to various health benefits of microgreens, which are rich in polyphenols and antioxidants, and present them as nutraceuticals. No toxic effects related to microgreens have been reported in the current literature. Studies have shown that the phytochemical and antioxidant properties of microgreens are affected by factors, such as light conditions, substrate, temperature, and seed genotype. The dimensions of these effects remain unclear. For this reason, more studies are needed. On the other hand, microbial contamination caused by environmental factors in microgreens is a critical issue, and therefore appropriate sanitation methods should be developed.

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