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Microgreen: A tiny plant with superfood potential

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ABSTRACT

The design of novel and functional foods is a major driver of innovation in the food industry, which strives to meet consumer's rising demand and expectations for healthy foods. In recent years, microgreens have received popularity as functional foods due to their high-density nutrients and bioactive or secondary metabolite content. The morphology of microgreens is comprised of well-developed cotyledonalary leaves, immature true leaves, and a central stem. The scientific literature has documented numerous studies on microgreens such as nutritional content assessment, metabolite accumulation, nutraceutical potential, and shelf life enhancement. Physical, chemical, biological, and cultivation factors significantly increased the microgreen's photosynthetic efficiency, growth, nutrient profile, antioxidant activity, and metabolite content. Using omics data, scientists have investigated the underlying molecular mechanism and potential gene(s) associated with nutrients, specialized metabolites, stress resistance, shelf-life enhancement, and disease resistance in nutraceutical plants.

1. Introduction

In the 21st century world, microscale vegetables have become increasingly popular due to their high nutritional value as well as bioactive enrichment (Ayoub, 2003). Microgreens have received a fair share of scientific and industrial attention, particularly considering their ready-to-eat property and high nutraceutical potential (Jambor et al., 2022). Microgreens are vegetable greens (not to be confused with - sprouts or green shoots) and are harvested just after the development of cotyledonalary leaves with one set of true leaflets (Jambor et al., 2022). In the era of global health consciousness, microgreens have been incorporated into people's diet due to their ability to fill nutritional gaps and health maintenance. Considered to be incredibly nutritious, microgreens are also known as "superfoods" and may be harvested in between a week to three weeks (Zhang et al., 2021; Jambor et al., 2022). Microgreens are well-suited for use as salad or edible garnishes for soups, sandwiches, and a variety of main dishes due to their distinctive flavors, appealing hues, and delicate textures. The use of a different variety of microgreens species can add visual and gustatory appeal to a dish. In addition, microgreens are ideal for indoor cultivation and symbolize a global shift toward climate-controlled farming (Riggio et al., 2019). Also, the short harvesting period and high market value of microgreens make them valuable controlled environment agri-crops (Wood, 2019)). In the review of literature, various studies have been executed on microgreens with special emphasis on their nutritional quality and characterization, phytochemical analysis, and diet supplements, thus promoted as a superfood (Marchioni et al., 2021; Zhang et al., 2021; Jambor et al., 2022). The literature also found that biotic and abiotic elicitors significantly regulate and enhance the production of various metabolites or bioactives in microscale vegetables. In addition, physical factors such as light (quality and quantity), humidity, temperature, substrate, cultivation strategies, seed density, and shelf life, significantly affect the growth and nutrition aspect of microgreens (Ghoora, Babu, & Srividya, 2020a; Ghoora, Haldipur, & Srividya, 2020b).

The microgreens business is expanding rapidly, but it confronts a number of obstacles (Charlebois, 2019; Riggio et al., 2019). Similar to sprouts in many ways, microgreens have been linked to seven recalls in the United States and Canada. Three of the recalls were caused by *Salmonella*, and the other four were caused by *Listeria*. (Turner et al., 2020).

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Also, the major limitation associated with microgreens is the rapid deterioration of their quality after harvesting. Due to their high surface area, rapid respiration rate, and delicate leaves, microgreens have a short shelf life in post-harvest (Berba & Uchanski, 2012; Chandra, Kim, & Kim, 2012; Kou et al., 2013). As per the reports, different chemical treatments, modified atmosphere, pressure, packaging, light intensities, and temperature control have helped to preserve the quality, and nutritional content, and enhance shelf life (Ghidelli & Pérez-Gago, 2018). In addition, hydroponic and soil-less substrates are typically preferred for microgreen production due to their portability, perception of quality enrichment, and ease to use (Renna et al., 2018). In addition, with the use of omics approaches, scientists have successively explored the underlying molecular mechanism and potential gene(s) behind vital trait regulation, architecture, stress resistance, plasticity, adaptation, and postharvest modification in food plants. These signs of progress lay a theoretical and practical foundation for designing and enhancing the efficiency of micro-scale vegetables for a wide range of applications.

Therefore, the purpose of this review is to bring public awareness to the benefits of microgreens by providing background information on this area of study. The review is focused on five key concepts of microgreens. The review began by discussing the global status and market trends of microgreens. After that, various studies on cultivation strategies and growing conditions for microgreens production were comprised. Subsequently, the chemical composition and effect of elicitors on the enhancement of microgreens' essential nutritional components were discussed. Factor affecting microgreens' shelf life and health promoting effects were reviewed simultaneously. Subsequently, innovative omic-technologies such as food-omics and nutri-omics were also discussed, with a particular focus on the nutraceutical properties of microgreens. As evidenced by its high-density nutritional composition in microgreens, the review highlighted that microgreens can be served as a potential functional food with huge nutraceutical values for the well-being of human health. For this review, the literatures have been searched through Pub-Med, Google-Scholar, Sci-Finder, Web-of-Science, Science-Direct, Scopus, and google search databases. By searching the term "microgreen" into PubMed.gov, Scopus, and SciFinder® databases, a total of 145, 206, and 417 relevant literature records in English language were found between the years of 2005 and 2022, respectively.

2. Microgreens, sprouts and vegetables

Microgreens are young vegetables picked between 5 and 21 days after germination, on average with height between 1 and 3 inches (average 1.5 inch). It consists of a stem, cotyledonary leaf or leaves, and two juvenile true leaves. However, not all young leafy vegetables are considered as microgreens. These are generally collected later than sprouts and are smaller than baby greens. The harvest time is the primary distinction between baby greens, sprouts, veggies, and microgreens. Typically, baby greens are harvested in between 20 to 40 days, while microgreens are harvested as soon as their true leaflets were developed. The harvest time for sprouts is earlier than that of microgreens. Sprouts are consumed with their seeds, roots, stems, and young cotyledonary leaves. In comparison, microgreens are consumed without their roots. Microgreens are able to produce delicate textures and distinct flavors due to their duration of harvesting than sprouts or baby greens. However, vegetables are harvested when the plant has completed its vegetative or reproductive phase, or both. In general, microgreens have more minerals and micronutrients than fully grown plants. This means that even small amounts of microgreen may have the same nutritional effects as larger amounts of fully-grown plants. The

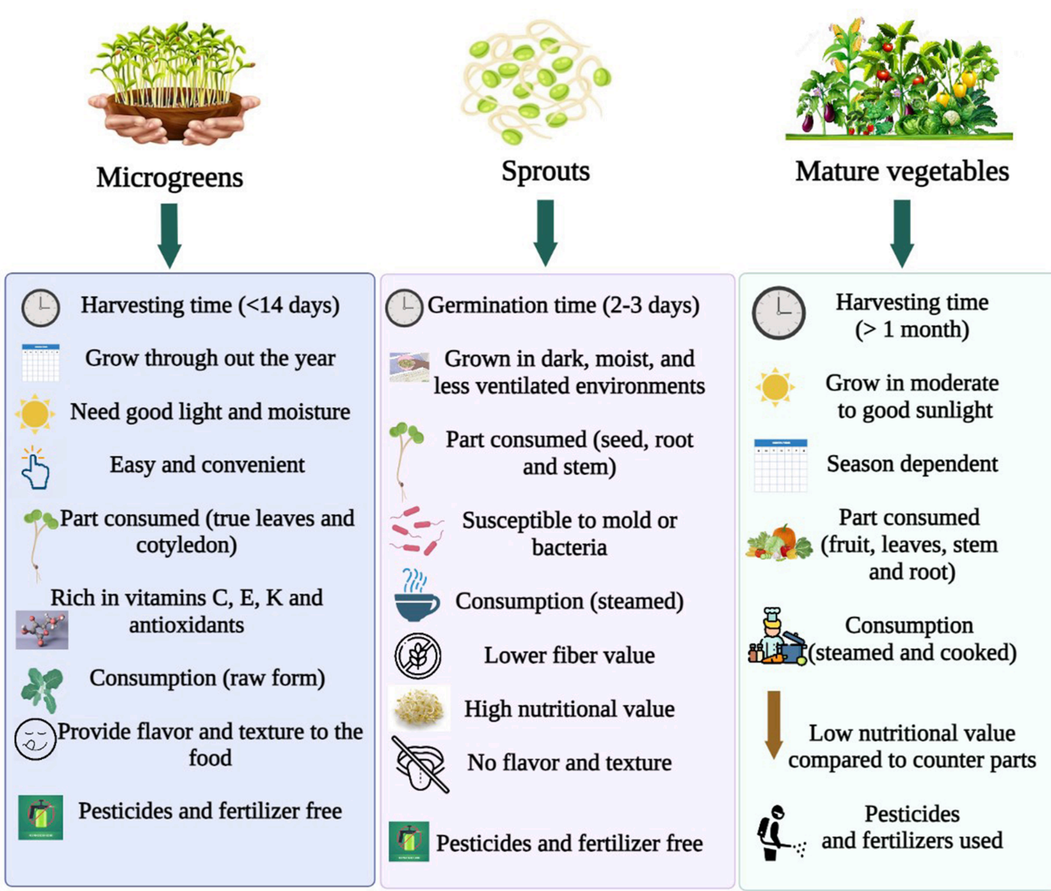

Fig. 1. Characteristics and properties of microgreen, spouts and matured vegetables. The images were made using BioRender software (https://www.biorender.com/).

basic difference between microgreen, sprouts and vegetables are represented in Fig. 1.

3. Microgreens: Global status and market trends

Due to its various health benefits and nutrient-dense properties, as well as the rapid adoption of indoor farming in urban areas, the market of microgreens is on an increasing trajectory in worldwide (Pattnaik et al., 2020). The worldwide microgreens market is anticipated to expand by 7.6% per year by 2025, reaching $17,039.742 billion (Al-Kodmany, 2018). Globally, microgreens are gaining popularity due to their positive effects on human health and appearance, as they are 40 times more nutrient-denser than mature vegetables (Muchjajib et al., 2014). As an example, broccoli appears to play a significant part in the growth of the microgreens industry due to its numerous healthy and nutritive properties. According to the report of Food and Agriculture Organization (FAO) in 2017, only China and India have produced ∼ 10.4 and 8.4 million metric tonnes of broccoli microgreen, respectively. In comparison, the United States, Spain, Mexico, and Italy collectively held less than 1 million metric tonnes (Parr et al., 2017). Microgreens, one of the most frequent crops grown indoors, scored 60% profitability due to high income (Paraschivu et al., 2021). Also, among profitable indoor crops, microscale vegetables had the highest profit margin (40%). Furthermore, microgreens grew by 26% in large indoor farms and by 10% on small farms, following an upward trend, and are expected to grow by 6% each year in the future (Paraschivu et al., 2021). The South and North regions of the United States had the highest cultivation of microgreens in greenhouses, recording 71% and 59% profitability in 2020. However, the progression of the microgreens market to its true development potential is contingent on consumer behaviour and income level.

4. Growing conditions

In this section, different factors affecting the growth and quality of microgreens, including substrate, seed sowing density, light exposure, and cultivation strategies are discussed (Murphy and Pill, 2010). Different factors that affect the production of microgreen are highlighted in Fig. 2. Also, the use of different substrates and systems for the cultivation of microgreen are represented in Table 1.

4.1. Substrate

Various substrates have been used to grow microgreens, and their influence on yield and nutritional quality has been studied (Lee et al., 2004). In a study, three different substrates - vermiculite, cotton, and jute fiber were used to grow microgreens of *Ocimum basilicum* L., *Ocimum basilicum* var. Purpurecsens and *Eruca sativa* Mill. in a Micro

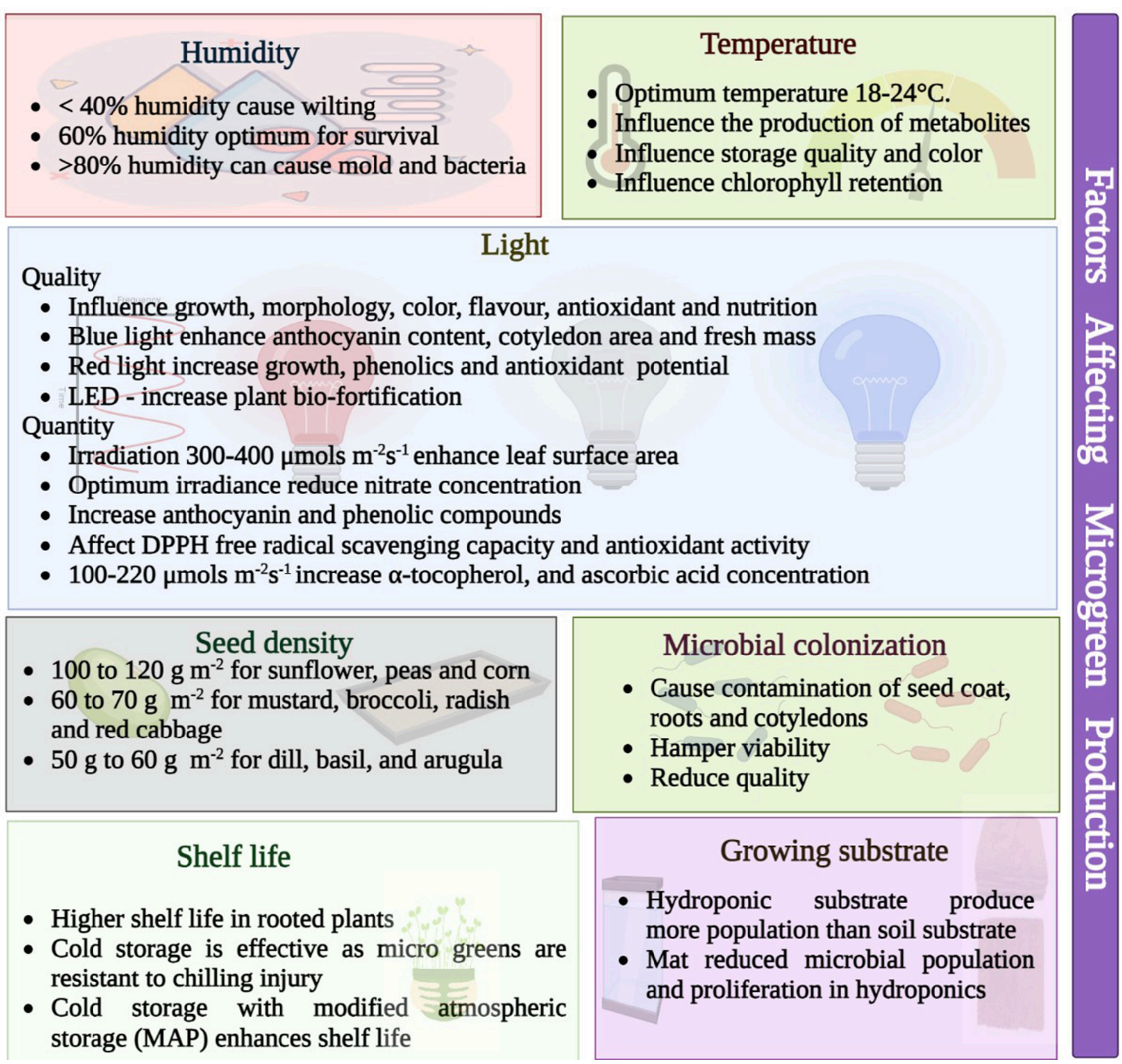

Fig. 2. Major factors (humidity, temperature, light, seed density, microbial colonization, shelf life, and growing substrate) affecting the production of microgreens. The images were made using BioRender software (https://www.biorender.com/).

Table 1
Different substrates and cultivation systems used for the production of microgreens.

Microgreens	Botanical name	Family	Substrate / Cultivation systems	References
Arugula	*Eruca vesicaria* L. Cav. subsp. *sativa*	Brassicaceae	Rockwool under greenhouse	Murphy and Pill., 2010
Basil	*Ocimum basilicum* L.	Lamiaceae	Rockwool, vermiculite, cotton, and jute fiber	Bulgari et al., 2017; Bulgari et al., 2021; Mezeyova et al., 2022
Beetroot	*Beta vulgaris subsp. vulgaris*	Amaranthaceae	Soil and mat cultivation	Lee et al., 2004
Beetroot	*Beta vulgaris* subsp. *vulgaris*	Amaranthaceae	Soil based	Ramya et al., 2022
Cabbage	*Brassica oleracea* var. *capitata*	Brassicaceae	Soil based under greenhouse	Sun et al., 2013
Cabbage savoy	*Brassica oleracea* L. var. *capitata*	Brassicaceae	Soil based under growth chamber	Kamal et al., 2020
Cauliflower	*Brassica oleracea* var. *botrytis*	Brassicaceae	Soil based under growth chamber	Guo et al., 2014
China rose radish	*Raphanus sativus* L.	Brassicaceae	Hydroponics system	Xiao et al., 2022
Chinese cabbage	*Brassica pekinensis*	Brassicaceae	Soil based under greenhouse	Hu et al., 2015
Chinese spinach and Joseph's coat	*Amaranthus tricolor*	Amaranthaceae	Soil based under greenhouse	Ebert et al., 2014
Cucumber	*Cucumis sativus*	Cucurbitaceae	Soil based	Ramya et al., 2022
Fenugreek	*Trigonella foenum-graecum*	Fabaceae	Cocopeat	Ramya et al., 2022
Field mustard	*Brassica rapa* L.	Brassicaceae	Rockwool under green house	Mezeyová et al., 2022
Green daikon radish	*Raphanus sativus* L. var. *longipinnatus*	Brassicaceae	Hydroponics system	Xiao et al., 2022
Green gram	*Vigna radiata* L.	Fabaceae	Soil based cultivation	Ramya et al., 2022
Lettuce	*Lactuca sativa*	Asteraceae	Soil based greenhouse	Pinto et al., 2015
Lettuce	*Lactuca sativa*	Compositae	Sphagnum moss	Ramya et al., 2022
Magenta spinach	*Spinacia oleracea* L.	Chenopodiaceae	Soil based cultivation	Xiao et al., 2022
popcorn shoots	*Zea mays* L.	Poaceae	Soil based cultivation	Xiao et al., 2022
Radish	*Raphanus sativus* L.	Cruciferae	Rockwool, White sphagnum peat, Coco coir	Thuong and Minh, 2020; Mezeyová et al., 2022
Red sorrel	*Rumex acetosa* L.	Polygonaceae	Soil based cultivation	Xiao et al., 2022
Tatsoi	*Brassica narinosa* L. var. *rosularis*	Brassicaceae	Soil and mat cultivation under growth chamber	Kamal et al., 2020
Turnip	*Brassica rapa* L. var. *rapa*	Brassicaceae	Soil and mat cultivation under growth chamber	Kamal et al., 2020
Vine Spinach	*Basella alba*	Basellaceae	Soil and mat cultivation under growth chamber	Muchjajib et al., 2014

Experimental Growing System (MEG) fitted with LED lamps for light supply. In addition to that, several other substrates are also available to use further as primary medium or in combinations, for example, coco peat, coconut fiber, coconut coir dust, coconut husks, sand, jute fiber, vermicompost, sugarcane filter cake, peat and white sphagnum peat substrates (Lester et al., 2010b). The three microgreens varied in nutritional quality, with red basil accounting for high antioxidant compounds on vermiculite and jute fiber media. At the same time, the qualitative parameters were found to be species-dependent (Bulgari et al., 2021).

4.2. Seed sowing density

Seed sowing density is a vital factor for microgreens growth because it directly linked to resources utilization like space, water and dissolved nutrients. Researchers used arugula microgreens to test four different sowing rates (50.25, 100.5, 150.75, and 201 g m^{-2}). There were linear relationships between the rate of sowing, the number of shoots per square metre, and the fresh weight of shoots per square metre were observed. The same results were found in a study that used beet microgreens. In another study, the number of seeds had a significant effect on the number of fresh shoots that radish microgreens grew on white sphagnum peat and coco coir. The fresh radish with higher number of shoots were grown in 8 seeds per cell density (approximate 109 g seeds) (Huang et al., 2016). As per the review research, following seed density were recommended for different microgreens; 100 to 120 g m^{-2} (sunflower, peas, and corn), 60–70 g m^{-2} (mustard, broccoli, radish, and red cabbage) and 50–60 g m^{-2} (dill, basil, and arugula). However, to date limited studies have been executed to test the seed densities of microgreens in different cultivation systems. Further research will also require to relate effect of seed density on the quality biomass production in microgreens.

4.3. Light conditions

Light (quality and quantity) is significant factors that responsible for microgreen growth and development, and simultaneously modulate the biosynthesis of specific defense-related secondary metabolites (Appolloni et al., 2022). As per the report, red light-emitting diode (LED) (638 nm) regulates the accumulation rate of ascorbic acid, anthocyanins, and, phenolic compounds in amaranth (Alrifai et al., 2019). In arugula, high-pressure sodium (HPS) lamp (max 660 nm) and blue LED (420–450) increased the isorhamnetin- diglycoside, luteolin- glycoside derivatives, and apigenin derivatives content. In basil, UV-A (390 nm), red LED (638 nm), blue LED (420–447 nm), and their synergistic effect increased the level of vitamins, phenols, flavonoids, carotenoids, chicoric acid, α-tocopherol, anthocyanins, lutein, and anthocyanins content. However, red (638–660 nm), blue (447 nm), far-red (731 nm), and UV-A (366–402 nm) light regulates the level of total phenol, flavonoids, anthocyanins and α-tocopherol in beet plant microgreen. The blue (470 nm), red (660 nm), and white light resulted in increased level of glucosinolates, phenols, flavonoids, xanthophyll, carotene and anthocyanin in kale microgreen. In case of broccoli, blue (470 nm), and 4red/1blue (622–632/442–452 nm) LED enhanced the level of antioxidant, and pigment content. However, in cabbage, coriander, mizuna, parsley and pea microgreens, light spectrum such 84% red (638 nm): 7% far-red: 9% blue (400–800 nm) LED enhanced the overall phytochemical composition (majorly antioxidant compounds). The synergistic effect of red, blue and far-red spectrum resulted in the enhancement of total anthocyanins and phenolic compounds in khohlrabi microgreen. In case of mustard microgreen, the red, blue, green yellow, orange, far-red and their combined effect increased the level of antioxidant compounds, carotenoids, tocopherol, lutein, neoxanthin, violaxanthin, lutein, and zeaxanthin content. Similarly, different light spectrum (range: 400–750 nm) also enhanced the secondary metabolites content in pac-choi, orach-tatsoi, and borage lettuce microgreens. Success in this field will also largely depends upon the proper utilization of rapidly developing LED technology for the production and enhancement of bioactives in microgreens.

4.4. Soil-less cultivation

The working principle or use of aquaponic, hydroponic (NFT and DWC) and aeroponic system for the cultivation of microgreen plants is represented in Fig. 3. Moraru et al. (2022) have reviewed the trial protocol for evaluating hydroponic microgreens cultivation platforms. According to the review report, the following environmental conditions are required for quality microgreen production (basil, lettuce, and brussels) in a hydroponic system: light (400 W), photoperiod (10–20 h), light intensity (300–500 mol m^{-2} s^{-1}), spectrum (440–700 nm), temperature (15–25 °C), humidity (75–80 %), nutrient solution pH (6.0–6.8), electrical conductivity (1.2–1.8 ms^{-1}), dissolved oxygen (6–6.5 mg L^{-1}), and solution temperature (18–20 °C). In the study of Ciuta et al. (2020), ebb & flow benches were compared to a vertical hydroponic system during the cultivation of microgreen. Also, the mixture of peat and perlite (ratio: 70:30) was compared to cellulose substrate. In comparison to the cellulose substrate, the peat and perlite mixture demonstrated a marginally higher germination rate. Small differences in harvesting height and weight of red radish microgreens were noticed. However, the vertical hydroponic system produced higher biomass in comparison to the growth benches. In addition, the vertical hydroponic system produces somewhat more growth in per unit area than the ebb-and-flow bench system. Weber (2016), revealed that lettuce (2.7 times) and cabbage (2.9 times) microgreens were more nutrient-denser than mature counterparts. In hydroponic-grown microgreens of sweet basil, Puccinelli et al. (2019) found a greater germination index, selenium (Se) content, and antioxidant capacity. In a study by Gerovac et al. (2016), three Brassica microgreens were cultivated in hydroponic tray systems on multilayer shelves. The results revealed that the total dry weight of Brassica microgreen varieties was increased when the light intensity increased from 105 to 315 μ mol m^{-2} s^{-1} (Gerovac et al., 2016). The study

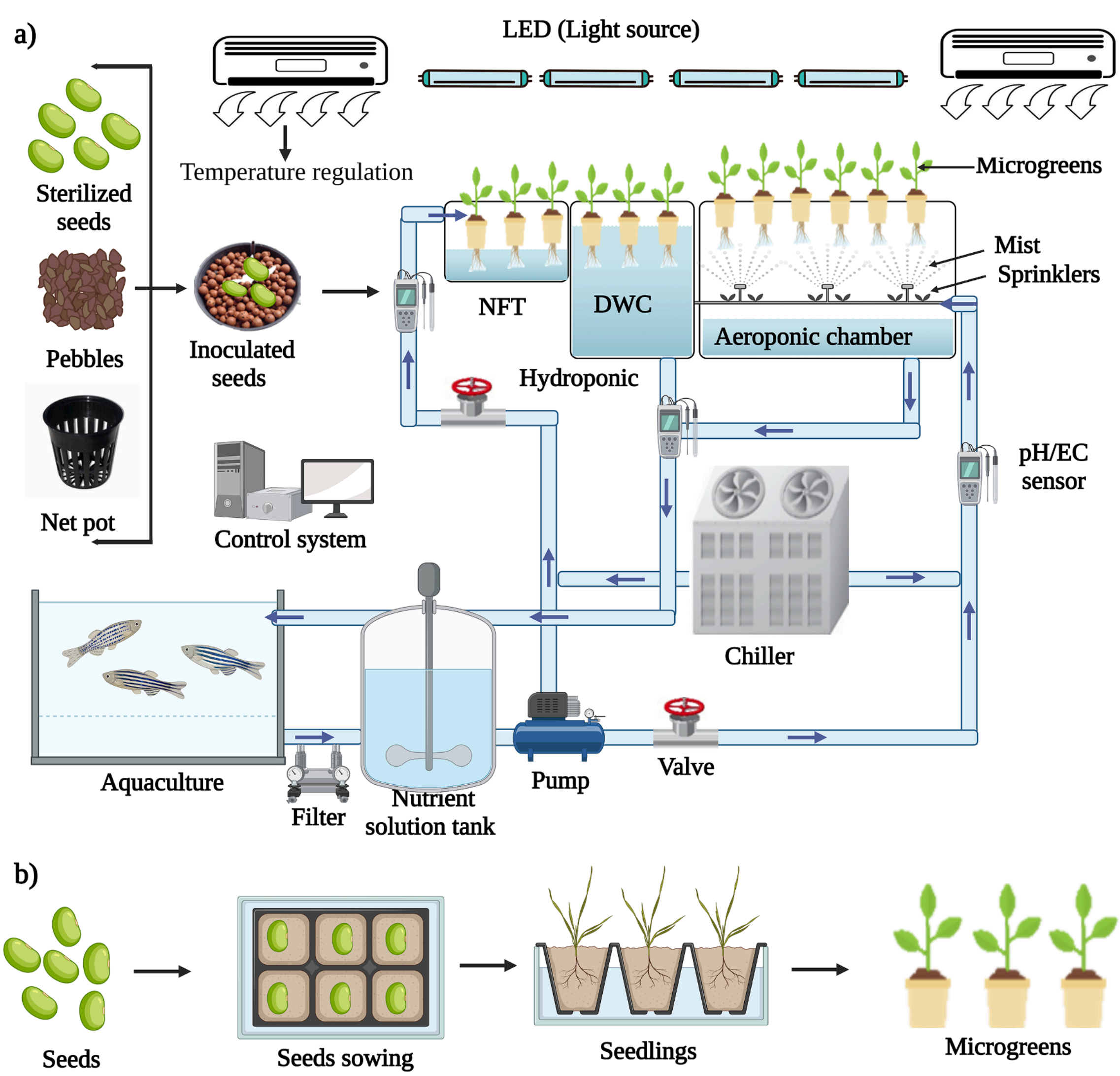

Fig. 3. Different cultivations systems for the production of microgreens. a) aquaponic, hydroponic (NFT: nutrient film technique; DWC: deep water culture), and aeroponic cultivation system. b) soil-based or solid substrate-based cultivation. The images were made using BioRender software (https://www.biorender.com/).

of Bulgari et al. (2017) provided reports on the yield, mineral absorption, and quality of basil, Swiss chard, and rocket microgreens grown in a hydroponic system. Compared to data reported in the literature for the same species hydroponically grown but harvested at the adult stage, the yield of these microgreens was approximately half, with a lesser dry matter percentage but a greater shoot/root ratio. They had high concentrations of certain minerals, but their nutrient uptake was restricted because of their low produce. The concentrations of nitrates, chlorophylls, carotenoids, phenols, and sugars were lower when compared to those typically measured in infant leaves or mature vegetables of the same species. Therefore, microgreens appear to be innovative and fascinating low-nitrate salad crops requiring little fertiliser. Nonetheless, an increase in yield and nutraceutical compound concentration would be desirable. The sensory attributes, nutrients content and antioxidant activity of microgreens grown in hydroponic and soil (commercial vs. local farm) were compared by Tan et al. (2020). The study stated that soil-grown microgreens possessed a significantly higher vitamin C concentration than hydroponically-grown microgreens. However, with the usage of environmental and fertigation-controlled soil-less farms, we can modulate the nutritional and phytochemical profile of microgreens.

Recently, it has also been demonstrated that microgreen growing under hydroponic systems are vulnerable to pathogen infections (Reed, Ferreira, Bell, Brown, & Zheng, 2018). Xiao et al. (2014a) reported that *E. coli* have been observed in high proliferate rate on radish microgreens under hydroponic cultivation. Di Gioia et al. (2017) found that recycled fibre mats and microgreens grown on them had lower microbial populations than peat-based combinations under soilless conditions. It has been observed that the type of growing media and substrate significantly influenced the growth of *Salmonella* in microgreens (Reed et al., 2018). Hydroponic with substrate pads influenced the growth of *Salmonella* as compared to the other studied growth media. Wang et al., (2015) investigated the *Listeria monocytogenes* growth in 10 days old microgreen, this study revealed that *Listeria monocytogenes* growth on the seed coats grew by 0.7 and 1.3 logs in soil-based and hydroponic systems, respectively. Wang and Kniel (2016), assessed the capacity of the murine norovirus (MNV) to invade from roots to edible parts of kale and mustard microgreens. They have been discovered persistently elevated amounts of MNV viral RNA in edible tissues. It has been observed that the contaminated seeds are the responsible for spatial distribution of bacterial cells on various parts of microgreen plants (Maclean et al., 2009). In this regard, ultraviolet and blue spectrums have the potential to improve the food safety of hydroponically grown microgreens by treating the water as it flows (Maclean et al., 2009; McKenzie et al., 2014; Kim et al., 2016). Further utilizing the explored research in hydroponic cultivation and light spectrum could be helpful to cultivate quality microgreen production in commercial scale soil-less systems. Also, the problem related to microbial contamination can be overcome by utilizing tissue culture and other biotechnological approaches for microbes/virus free seed production.

5. Chemical composition in microgreens

In recent years, the demand of microgreens has increased due to their nutritional as well as phytochemical components (Chandra et al., 2012; Xiao et al., 2012; Kou et al., 2013). This section delivered the comprehensive discussion on vitamins, carotenoids, total sugars, minerals, and phytochemical contents in microgreens (Table 2).

5.1. Vitamins

Phylloquinone (Vitamin K1) is typically found in high concentrations in spinach, kale, and broccoli microgreens (Choe et al., 2018). As previously reported, the phylloquinone contents in the 25 different microgreens ranged from 0.6 to 4.1 μg/g (FW). Among all, garnet amaranth accumulated higher phylloquinone content (4.1 μg g^{-1} FW), while magenta spinach accumulated lowest content at 0.6 μg/g FW. Among different colors, green/bright red microgreens had higher quantities of phylloquinone, whereas yellow microgreens had lower content. In addition, the phylloquinone content in microgreens is significantly higher than that of mature counterparts. Total-ascorbic acid (TAA), free-ascorbic acid (FAA), and dehydro-ascorbic acid (DAA) have also been quantified in microgreens. The TAA content in different microgreens were ranged from 20.4 to 147 mg 100 g^{-1} (FW). In this, red cabbage accumulated highest TAA content, while in sorrel microgreen lowest TAA content was reported. Also, red cabbage microgreens contained six times more vitamin C compared to mature counterparts. In addition, garnet amaranth has a significantly higher TAA content than

Table 2
Nutritional and phytochemical components in microgreens.

Micro-green crops	Nutritional components	Phytochemical components	References
Amaranthus, Bottle gourd, cucumber, jute, palak, poi, pumpkin, radish and water spinach	Minerals (K, Fe, Mn, Zn and Cu)	Phenolics, flavonoids and ascorbic acid	Yadav et al., 2019
Buckwheat	Vitamins (B1, B2, B6, and E), proteins, minerals (Zn, Cu, Mn, Se, K, Na, Ca, Mg), starch and dietary fibre	Flavonoids, Fagopyrins, carotenoids, α-tocopherol and ascorbic acid	Christa et al., 2008; Janovská et al., 2010
Broccoli, daikon, mustard, rocket salad, and watercress	Vitamins (E, A, K), minerals (N, K, Ca, Fe) and chlorophyll contents	Carotenoid, Isothiocyanates polyphenols, anthocyanin, monoterpene hydrocarbons, phytol and ascorbic acid	Marchioni et al., 2021; Domínguez et al., 2010
Radish	Vitamin (E), carbohydrates, protein and minerals (Ca, K and P)	Carotenoid, ascorbic acid, amino acid content, total phenols, flavonoid and anthocyanins	Gamba et al., 2021
Lettuce	Minerals (Ca, Mg, Fe, Mn, Zn, Se and Mo)	Polyphenols, carotenoids and chlorophyll	Pinto et al., 2015; Shi et al., 2022
Coriander	Vitamins A and minerals	Carotenoids, phenols, vitamin C and flavonoids	Nath et al., 2015
Oriental mustard	Minerals (K, Ca, Na, Mg, Fe, Mn and Zn)	Phenolic compounds and carotenoids	Rahmani et al., 2020
Chickpea	Carbohydrates, proteins, fat, fiber, pantothenic acid (B_5) and pyridoxine (B_6)	Carotenoids, lutein, isoflavones	Sotelo et al., 1987; Jukanti et al., 2012
Salad burnet	Carbohydrates, proteins and fat	Phenolic compounds, α-tocopherol	Ayoub., 2003; Ceccanti et al., 2023
Fenugreek	Potassium, and minerals (K, Ca, Na, Na, Cu, Fe and Cu)	Phenolic and flavonoids	Aylanc et al., 2020; Dhull et al., 2021
Foxtail amaranth	Dietary fiber, proteins, carbohydrates, vitamin and minerals (Fe, Mn, Cu, Zn, Na, Mo, B, K, Ca, Mg, P and S)	Ascorbic acid, carotenoids and flavonoids polyphenols	Sarker et al., 2020
Arugula	Phylloquinone, and β-carotene	Glucosinolates, ascorbic acid and total carotenoids	Yang et al., 2021
Chicory	Minerals (Mg, Zn), protein, vitamins (A) and minerals (K, Ca and P)	Total flavonoids, total phenolic, Ascorbic acid	Abbas et al., 2015

its mature stage. It has also been observed that m microgreens of kale and mustard were found to contain less ascorbic acid than their full-grown stages (de la Fuente et al., 2019). However, red-cabbage microgreens had the increased content of vitamin C, whereas green daikon-radish microgreens had the increased content of vitamin E. Lester et al. (2010a) reported that the baby spinach contained higher content of vitamins C, B9, and K1. In another study, the green daikon radish has been reported with higher content of tocopherol (vitamin E) in both α (87.4 mg 100 g^{-1} FW) and γ (39.4 mg 100 g^{-1} FW) types. In addition, cilantro, opal-radish, and pepper-cress microgreens have been reported with increased level of α- and γ-tocopherols. Even-though, golden pea tendrils were reported with lower level of α (4.9 mg 100 g^{-1} FW) and γ (3.9 mg 100 g^{-1} FW) tocopherol content. These contents have been reported higher than their mature counterparts. As per the report of Marchioni et al. (2021) reported that mustard has a higher vitamin C content (606.87 μg/g FW) than broccoli, daikon, and watercress microgreens (124.1–137.52 μg g^{-1} FW). In comparison, rocket salad contained only 29.67 μg g^{-1} FW of vitamin C. Also, mustard had a higher ascorbic acid concentration (366.07 g g^{-1} FW) compared to rocket salad (25.86 μgg^{-1} FW) and watercress (38.55 μgg^{-1} FW).

5.2. Carotenoids

Red sorrel accumulated highest content of carotene (12.1 mg 100 g^{-1} FW), whereas golden pea tendrils and popcorn microgreens had the lowest (0.6 mg100 g^{-1} FW). In addition, Red cabbage microgreen (11.5 mg 100 g^{-1} FW) accumulated 260 times higher carotene than their mature stage (0.044 mg 100 g^{-1} FW). Also, two important carotenoids present in blood are lutein and zeaxanthin. Popcorn microgreen had the lowest lutein/zeaxanthin content (1.3 mg100 g^{-1} FW). In another study, the lutein and zeaxanthin content in mature cilantro and red cabbage is 0.90 and 0.30 mg 100 g^{-1} FW, respectively. However, in cilantro (10.1 mg 100 g^{-1} FW) and red cabbage (8.6 mg 100 g^{-1} FW) microgreen reported 11.2 to 28.6- fold greater lutein or zeaxanthin content than their mature stages. Among 25 different microgreens, cilantro exhibited the highest level of violaxanthin (7.7 mg 100 g^{-1} FW), whereas popcorn had reported lowest content (0.9 mg100 g^{-1} FW). In contrast, the carotenoid level of kale microgreens was lower than that of mature kale. Klopsch et al. (2018) also discovered that mature pea and lupin leaves contained more carotenoids than pea and lupin microgreens. However, broccoli and cauliflower microgreens had higher quantities than mature counterparts (Xiao et al., 2019). Niroula et al. (2019) found that the higher carotenoid content in wheat and barley microgreens. Lester et al. (2010b) also found that baby spinach microgreen contains more concentrations of carotenoids than the mature leaves. The total carotenoid content was considerably lower in watercress (96.9 g g^{-1} FW) than in the other Brassicaceae microgreens (range: 175–217 μg g^{-1} FW) (Marchioni et al., 2021).

5.3. Total sugar contents

Researchers analyzed and evaluated the total sugar content in six microgreens, including bull's blood beet, China-rose-radish, Dijon-mustard, opal-basil, pepper-cress, and scarlet amaranth (Xiao et al., 2019). China-rose-radish had the highest sugar content (10.3 g kg^{-1}) than other microgreens. However, sugar content (g kg^{-1} FW) in peppercress (8.8), Dijon mustard (7.7), bull's blood beet (4.4), opal basil (2.0), and scarlet amaranth (1.7) were reported. In comparison, the sugars level of mature veggies was greater than that of microgreens. For instance, mature peppercress and red amaranth contained 44 and 17 g kg^{-1} FW of sugar content, respectively (Xiao, 2013). Marchioni et al., (2021) study found that the highest levels of reducing sugars were found in watercress (8.44 mg GLU g^{-1} FW) and rocket salad (7.98 mg GLU g^{-1} FW), while daikon and broccoli contained nearly half as much (4.47 and 4.47 mg GLU g^{-1} FW, respectively). Mustard had the highest sugar content by a substantial margin (58.11 mg GLU g^{-1} FW), which was threefold higher than that of broccoli, rocket salad, and watercress, and twofold higher than that of daikon.

5.4. Minerals

Recent research indicates that microgreens are a rich source of minerals. Weber (2017), found that broccoli microgreens contained 1.15 to 2.32 times more minerals (P, K, Mg, Mn, Zn, Fe, Ca, and Cu) than mature broccoli. Waterland et al. (2017) also reported mineral concentrations in the kale microgreen were higher in the early phases compared to later stage. In this, baby leaf microgreen had more minerals per unit FW than adult kale. Brassica microgreens are rich source of macro-elements (K and Ca) and microelements (Fe and Zn). According to an analysis of thirty cultivars of Brassicaceae family, the result ravelled that microgreen forms accumulated more minerals than their mature counterparts (Xiao et al., 2016). Pinto et al. (2015) found that microgreen lettuce has a higher (number and quality) mineral content (Ca, Mg, Fe, Mn, Zn, Se, and Mo) than mature lettuce. It has been observed that microgreens of basil and Swiss chard were rich in potassium and magnesium (Kyriacou et al., 2019). Similar results have been observed in Xiao et al. (2016) report, assessed the mineral content of baby leaf microgreen, including Na, K, P, Ca, Mg, Fe, Mn, Zn, Cu Se, and Mn.

5.5. Polyphenols and glucosinolates

As per the repot, microgreen red cabbage (71.01 μmol g^{-1}) contained more polyphenols than mature stage (50.58 μmol g^{-1}) (Huang et al., 2016; Wu et al., 2021). In addition, the concentration of glucosinolates was also higher in microgreen (17.15 μmol g^{-1}) compared to mature counterparts (8.30 μmol g^{-1}) (Huang et al., 2016; Wu et al., 2021). Sun et al. (2013) analyzed the polyphenols in five microgreens variety of Brassica and identified 165 phenolic compounds. The results indicated that the polyphenol profiles of microgreens of Brassica species tended to be more complicated than those of mature plant counterparts. The microgreens species of family Amaranthaceae, Apiaceae, Asteraceae, Basellaceae, Boraginaceae, Brassicaceae, Convolvulaceae, Cucurbitaceae, Lamiaceae, Linaceae, Malvaceae, Onagraceae, Plantaginaceae, Polygonaceae, and, Portulacaceae have higher phenolic content than mature counterparts (Ebert, 2022). In the report of Marchioni et al., (2021), the highest content of total polyphenol (3.63 μg g^{-1} FW) was quantified in broccoli, followed by daikon, watercress, and rocket salad microgreens. In mustard microgreen lowest content (1.02 μg g^{-1} FW) of polyphenol was reported.

5.6. Chlorophyll pigment content

The growth and quality of microgreens can be assessed by their chlorophyll content (Marchioni et al., 2021). In the report of Marchioni et al. (2021), mustard had the highest concentration of chlorophyll *a* (Chl a) at 982.3 μg g^{-1} FW, followed by broccoli, rocket salad, daikon, and watercress. Chlorophyll *b* (Chl b) content followed a similar pattern, with mustard having the highest concentration (409.2 μg g^{-1} FW). The total chlorophyll content is the sum of the individual chlorophyll contents, with mustard having the highest and daikon the lowest. The Chl a/Chl b ratio was observed between 2.51 and 3.66; the generally accepted ratio that indicates optimal plant growth is between 2.51 and 3. In addition, mustard contained the highest concentration of anthocyanins (405.52 μg g^{-1} FW), followed by broccoli (172.51 μg g^{-1} FW). In contrast, the lowest levels were found in daikon and watercress (57.56 and 52.28 μg g^{-1} FW, respectively). The concentration of anthocyanin in rocket salad (42.26 μg g^{-1} FW) was statistically lower than that of the other microgreens. In the study of Kowitcharoen et al. (2021), the microgreens showed a total chlorophyll content range of 12.35 to 112.62 mg 100 g^{-1}. The smallest concentration was found in green peas, while the highest was detected in lentil microgreens. The results bear a close resemblance to a previous study of radish and fenugreek microgreens (Ghoora et al., 2020b). As per the report of Tan et al. (2020), local farm grown broccoli microgreen had significantly higher chlorophyll content (0.33 and 0.30 mg g^{-1}, respectively) than that from the commercial source (0.029 mg/g). The chlorophyll content of hydroponically grown samples from the local farm was higher than that of the soil-grown samples, but the difference did not reach statistical significance. Total chlorophyll content in lentil microgreen (2.45 mg g^{-1}), mung bean microgreen (4.07 mgg^{-1}), and chickpea microgreen (4.90 mg g^{-1} DW) were observed by (Kumar et al., 2023). The maximum content of Chl 616.63 mg 100 g^{-1} DM and 54.80 mg 100 g^{-1} DM were reported in wheat and barley microgreen, respectively (Niroula et al., 2019). As per the report of Kaur et al. (2022), the higer leval of total chlorophyll content range was observed in microgreen of chickpea (4.56–5.23 mg/g) followed by black gram (4.22–4.88 mg g^{-1}) and mung bean (3.42–3.96 mg g^{-1}). Ghumman et al. (2017) reported comparable chlorophyll content (4.62 mg/g) in freeze-dried juice powder of chickpea. While Malik et al. (2011) reported lower chlorophyll content (1.36 mg g^{-1}) in 10-day-old hydroponically grown mung bean plants.

5.7. Essential oil content

As per the study by Marchioni et al. (2021), the essential oils of broccoli, daikon, mustard, rocket salad, and watercress contain a total of 50 compounds. Daikon contained 96.4% of the identified compounds, whereas watercress contains 100%. Broccoli's essential oil was composed primarily of isothiocyanates (97%). The relative abundance of the 5-cyano-1-pentene compound among non-isothiocyanates compounds exceeded 1.0%. Among oxygenated diterpenes detected in Daikon, phytol was the most abundant chemical group (29.0%). essentialIsothiocyanates comprised over forty percent of mustard's essential oil, with allyl (22.7%) and 3-butenyl isothiocyanates (14.1%) being the most abundant. However, Phytol exhibited the highest relative abundance in this essential oil as a single compound, as it was detected at a relative abundance of 28.4%. Non-terpene derivatives accounted for 12.7% of the total composition, with (Z)-3-hexen-1-ol (7.2%) and its acetic ester (2.4%) constituting the majority. Only limonene was detected among monoterpene hydrocarbons, with a relative concentration of 3.6%. In arugula salad essential oil, myrcene (83.7%) and limonene (7.5%) were detected predominantly. The only members of the sesquiterpene hydrocarbons group were β-caryophyllene (4.4%) and α-humulene (1.3%). Over 65.0% of the essential oil of watercress was composed of isothiocyanates, with benzyl isothiocyanate being the only isothiocyanate detected. The second most abundant compound in the essential oil was benzyl nitrile, which accounts for up to 26.0%. Phytol detected in the essential oil of watercress and showed a relative concentration of 3.3%.

6. Delving into elicitors

Molecules of biotic or abiotic elicitors can bind to membrane-bound receptor proteins on plant cells. These receptors can identify the chemical pattern of elicitors and initiate intracellular defense signaling via the Octadecanoid pathway (Liu et al., 2018). This reaction increases

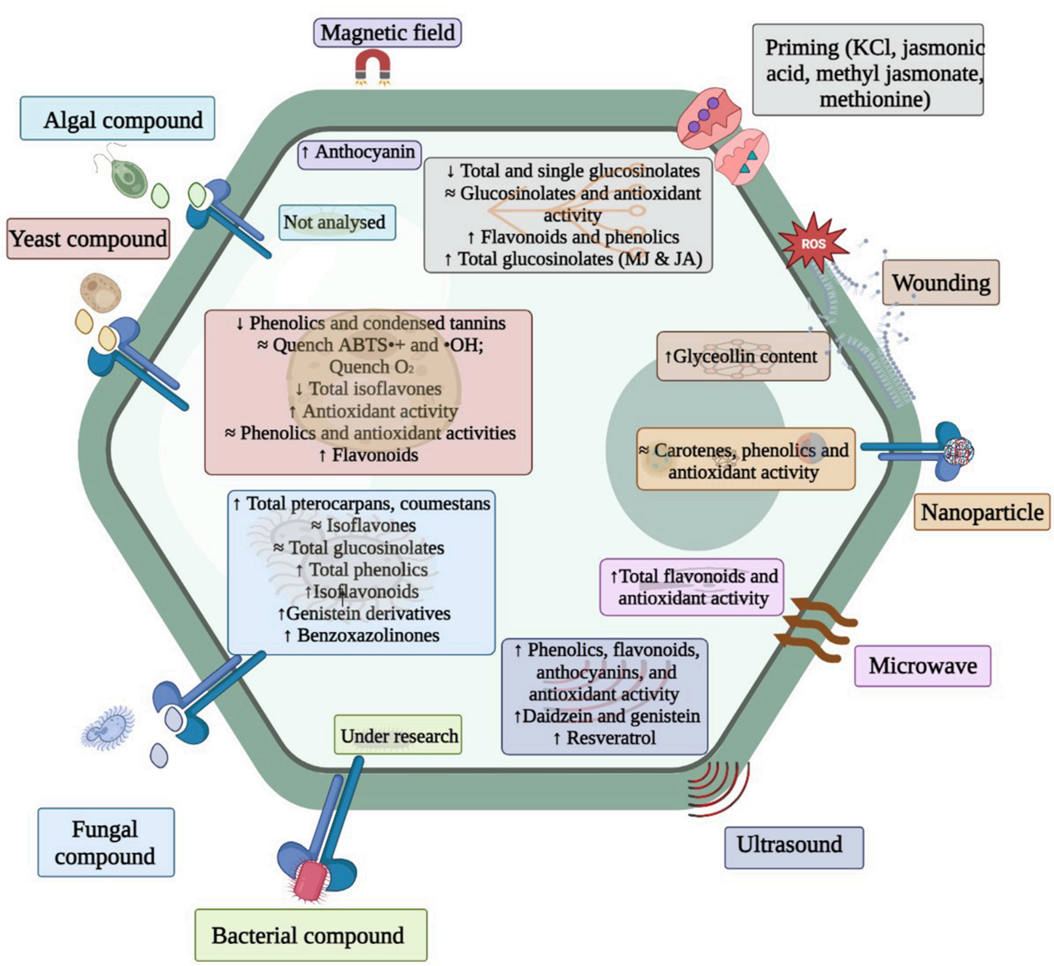

Fig. 4. Elicitors (biotic and abiotic) responses for the production of bioactive molecules in microgreens (cellular level). The images were made using BioRender software (https://www.biorender.com/).

the synthesis of metabolites that reduce damage and promote resilience to pests, diseases, and environmental stress. Recent reviews on elicitation strategies in microgreen vegetables were discussed by Liu et al. (2018), Galieni et al. (2020), Artés-Hernández et al. (2022). This section particularly discussed about the various elicitors and elicitation techniques for the production of secondary metabolites in microscale vegetables (Fig. 4). As per the reports of (Baenas, Villaño, García-Viguera, & Moreno, 2016; Hassini et al., 2017a) seeds of *Brassica oleracea* and *Raphanus sativus* primed with abiotic elicitors (KCl, methyl jasmonate, jasmonic acid, and methionine) resulted in increase of total flavonoids, phenolics and glucosinolates content. In addition, the physical factors also play an important role in the enhancement of phytochemicals in plants (Hassini et al., 2017b). In case of micro-scale microgreens, physical factors (wounding, ultra-sound, nano-particles, magnetic-field, micro-wave and clinorotation) resulted in the enhancement of glyceollin, phenolics, flavonoids, anthocyanins, antioxidant activity, isoflavones, resveratrol, and carotenes content in *Glycine max*, *Phaseolus vulgaris*, *Arachis hypogaea*, *Brassica oleracea*, *Fagopyrum esculentum*, and *Vigna radiata*, respectively. As per the review of literature, various studies have also been executed with the use of biotic elicitors for the enhancement of phytochemical in micro-scale vegetables. The use of fungal (*Rhizopus oryza*, *Fusarium graminearum*, *Fusarium oxysporum*, *Aspergillus oryzae*, and *Rhizopus oligosporus*) treatments significantly regulates the level of pterocarpans, coumestans, isoflavonoid, glucosinolates, stilbenoid, phenolics, flavonoids, genistein and benzoxazolinones contents in microscle vegetables such as *Glycine max, Sinapis alba, Brassica napus, Brassica juncea, Arachis hypogea, Vigna radiata, Phaseolus vulgaris, Glycine max, Lupinus albus, Lupinus angustifolius, Lupinus luteus, Arachis hypogaea, Phaseolus coccineus, Lablab purpureus, Vigna angularis, Vigna unguiculate, Psophocarpus tetragonolobus,* and *Triticum aestivum*, respectively. Similarly, use of yeast (*Lactobacillus plantarum*, and *Saccharomyces cerevisiae*) as elicitor also increased the level of secondary metabolites in microscale vegetables. However, the role of algae and bacterium on metabolites production in microgreens is not reported yet. Though, to date, elicitors have been generally used in alone but not in combination on microscale vegetables., However, their synergistic effects could also be studied to evaluate the effect on nutraceutical potential in microgreens under variable conditions and parameters.

7. Shelf life

Microgreen consumption has increased owing to public awareness of its unique colour, rich taste, and concentrated bioactive components (Hodges and Toivonen, 2008). Industrial manufacturing and marketing are constrained owing to their shorter shelf life and rapid product quality deterioration (Xiao et al., 2014b). Lower temperatures slow respiration, which reduces cellular metabolism in cotyledonary picked microgreen. On the other hand, low temperature also slows metabolic rates, which improves visual quality and shelf life (Mir et al., 2017). Microgreens can be preserved in several ways. Storage temperature and atmospheric conditions are two key methods for extending postharvest shelf life. Temperature management is the most important aspect in extending microgreens' shelf life (Xiao et al., 2014b). Furthermore, micro-greens' shelf life may also be extended through modified atmospheric packing which lowers oxygen, increased carbon-dioxide, and controlling partial pressure (Kim et al., 2004). Packaging and its manufacturing material also decrease the biological contamination rate of the products during storage. Previous studies suggested that 2 to 10 °C is the best temperature for the storage of microgreens like spinach, buckwheat, table beet, cabbage, celery, radish, pea, basil, broccoli, and lettuce. These microgreens also had a longer shelf life in polyethylene, polypropylene, and polyester bags. Optimized, sustainable washing and sanitizing methods are usually utilized to maintain microgreens' freshness, nutritional content, and shelf life. The calcium treatments influence microgreen phytonutrients, although preharvest treatments are much more effective (Kou et al., 2014). The calcium chloride (10 mM) concentration increased the superoxide dismutase and peroxidase activity in the microgreens. It also decreased the tissue electrolytes loss, and microbial growth during storage (Kou et al., 2014). Glucosinolates were the primary components in broccoli microgreens which were improved by 10 mM calcium chloride preharvest treatment and enhances shelf life (Lu et al., 2021). Postharvest (UV-B irradiation) and preharvest (10 mM calcium chloride) increased the overall glucosinolate content in microgreens and enhances shelf life (Lu et al., 2018; Lu et al., 2021). Organic acids like citric acid and ascorbic acid have been used to preserve physicochemical properties and inhibit microbial growth which did not influence the taste and flavour of produce (Rico et al., 2007). Under air or nitrogen environment, baby leaf spinach was subjected to cesium-137 g-radiation at 0.0, 0.5, 1.0, 1.5, and 2.0 kGy. Results revealed that increased irradiation doses did not affect phytonutrient concentrations (vitamin B9, E, K, and neoxanthin), however, 2.0 kGy substantially decreased total ascorbic acid, lutein/zeaxanthin, violaxanthin, and b-carotene (Lester et al., 2010b). According to Berba and Uchanski (2012), microgreens shelf-life can also depend on maturity level of seedlings at harvest. In this, for good shelf life, radish was harvested at 7 days, arugula (9 days), and red cabbage (11 days) to meet industry requirements. Radish microgreens had the lowest respiration rate and highest visual quality after first week. Radish, arugula, and red cabbage had visual shelf lives of 21 and 14 days at 4 °C, respectively (Berba & Uchanski, 2012). Relative humidity (RH) also affects fresh-cut product quality and shelf life. Quality and shelf life of microgreen suffer from dehydration and high humidity. 1-methylcyclopropene (1-MCP) has been shown to extend the shelf life of several fruits, vegetables, and edible flowers, however, to our knowledge these studies are lacking in microgreens.

8. Health promoting effects

Globally, vegetable and fruit eating habits, lowers the risk of several human diseases. Preliminary research on microgreens have emphasized on micronutrient and bioactive component enrichment. Some commonly eaten microgreens with equal or greater quantities of health-promoting micronutrients have been proven to indirectly prevent chronic illnesses. Few microgreens' therapeutic benefits have been directly validated in cell and animal models, but not in clinical studies with humans. Here, we have provided the various instances of the norm.

8.1. Anti-oxidant potential

Microgreens, which act as dietary carriers of naturally occurring antioxidant chemicals including polyphenols and vitamins. In fact, microgreens of *Vigna radiata* and *Cicer arietinium* exhibit more antioxidant activity when compared to seeds and sprouts (Ebert, 2022). Similarly, microgreens of cruciferous and umbelliferous were reported to have particularly high antioxidant capacities. Similarly, previous research tested on four genotypes of hydroponic Brassicaceae microgreens showed that soluble polyphenols and isothiocyanates were the primary contributors to the total antioxidant capacity (de la Fuente et al., 2019). Microgreen's antioxidant capacity may be increased via bio-enhancement and better illumination. Soybean microgreens treated with blue light or UV-A had increased antioxidant capacity and phenolic metabolites than the control (Zhang et al., 2019). Red light (638 nm) treatment increased antioxidants in basil (*Ocimum basilicum*) microgreens but not in parsley (*Petroselinum crispum*) (Samuoliene et al., 2016). Selenium biofortification at 0.25 and 0.50 mg L^{-1} in a hydroponic environment increased the antioxidant activity of wheat microgreen (Mezeyová et al., 2022). Naturally occurring polyphenolic substances with antioxidant capacity may reduce the brain's oxidative stress in Alzheimer's disease. Thus, antioxidant-rich microgreens with high polyphenol contents may protect against Alzheimer's disease and other age-related disorders including cardiovascular disease, cancer and diabetes. In both the DPPH and FRAP assays, daikon, broccoli, and watercress demonstrated the highest antioxidant activity, whereas rocket salad and mustard demonstrated substantially lower activities (Marchioni et al., 2021).

8.2. Cardiovascular disease

Cardiovascular disease is a serious health issue worldwide due to sedentary lifestyles and poor diets, yet microgreens intake may minimise the risk. Microgreens from red cabbage have been shown to alter the lipid and cholesterol levels. The study of Huang et al. (2016) reported that red cabbage microgreen supplementation reduces weight gain, low-density lipoprotein, triglycerides, and hepatic cholesterol ester levels, and liver inflammatory cytokines in mice. Concentrations of polyphenols and glucosinolates in red cabbage microgreens were 71.01 and 17.15 μmol g^{-1}, respectively. It has been shown that polyphenols and glucosinolates, in conjunction with dietary fibres, may bring cholesterol levels down (Złotek et al., 2019).

8.3. Anti-diabetic and anti-obesity activity

Blood glucose levels in diabetic patients may be controlled by both enzymatic inhibition and improved glucose uptake. Fenugreek microgreen, which contains significant amounts of polyphenols and other antioxidant chemicals, have reported antidiabetic effect at a concentration of 2 mg mL^{-1} by aqueous extract inhibition -amylase (70%) and increased glucose absorption in L6 cells (25%) (Sharma, Dhingra, & Koranne, 2020).

8.4. Anti-cancerous activity

According to previous research, a diet rich in fruits and vegetables may prevent cancer. Therefore, bioactive compound-rich microgreens may protect against cancer. For example, broccoli microgreens have four times more anti-cancerous aliphatic glucosinolates than its florets and mature leaves. A recent research on human colon cancer Caco-2 cells found that Brassicaceae microgreens had a significant anti-proliferative impact on cancer (De La Fuente et al., 2020). The antioxidants components present in Brassicaceae microgreens significantly decreased the proliferation of tumour cells by 10–12.8% (MTT assay) and 20–41.9% (Trypan-blue). It has also found that lesser, microgreens with lower ascorbic acid and antioxidant activity showed less responsive against cancer cell lines. Microgreens may regulate xenobiotic metabolism and inflammation, which may prevent cancer. The control of multiple carcinogenic pathways is uncertain, and very few clinical studies have shown that dietary polyphenols can fight cancer. Thus, additional research is needed on microgreens' cancer preventive measures.

8.5. Anti-inflammatory activity

Higher levels of polyphenols and glucosinolates in microgreens, are believed to modulate the immune system and prevent the aforementioned diseases (López-Chillón et al., 2019). Polyphenols and glucosinolates may inhibit the phosphorylation or ubiquitination of essential kinases in the NF-kB signal transduction pathway. Glucosinolates may inhibit the catabolism of nuclear factor kappa light polypeptide gene, thereby interfering with NF-kB (Lopez-Chillon et al., 2019; Subedi et al., 2019). Cyclooxygenase-2 (COX-2) upregulation can result in the destabilisation of an inflammatory process through the production of prostaglandin. However, different polyphenols found in microgreens may inhibit COX-2 activity (Subedi et al., 2019). According to previous reports, AhR also plays a crucial role in the regulation of the immune system. AhR also participates in the interleukin-27 (IL-27)-induced differentiation of FoxP3-IL-10-producing type 1 regulatory T-cells. Microgreens contain an abundance of AhR ligands in their phytochemical makeup. This indicates that indole-3-carbinol, along with other polyphenols and glucosinolates, can influence AhR-mediated immune responses and T-cell regulation (Wheeler et al., 2017; Subedi et al., 2019). In addition, Huang et al. (2016) proposed that the ability of red cabbage microgreens to reduce liver lipids, an excess of which is known to induce inflammatory responses, inhibits TNF-α production. Subedi et al. (2019) provided evidence that consuming broccoli microgreens modifies the immune system. Broccoli enriched with sulforaphane inhibited the NF-kB signalling pathway and inflammatory proteins including TNF-, IL-1, and prostaglandin E2 (PGE2).

9. Food-omics and nutri-omics

In recent decades, analytical tools have evolved from classical methods to more advanced and sophisticated methods that apply the latest discoveries in the field to food science. The term "Foodomics" was defined in 2009 as "a discipline that studies the Food and Nutrition domains through the application and integration of advanced omics technologies to improve consumer's well-being, health, and knowledge". However, especially Nutriomics techniques are utilised to analyse the effects of various diets on health promotion and disease risk modulation. These applications make it possible to pursue more ambitious goals, seeking to expand scientific knowledge and viewpoint. As a result, foodomics research has profited greatly, particularly in regards to the intricate relationship between food and health science. In foodomics, the omics approaches, such as genomics, transcriptomics, proteomics, metabolomics, nutri-genomics, and micro-biomics, as well as ion-omics, are crucial tools (Fig. 5). This will still allow us to unravel the immense complexity of the foodome, which has been described as the collection of all substances present in a food sample and/or in a biological system interacting with the researched food at a particular moment. Till date, very limited studies have been executed in the food-omics of microgreens. As per the report of Naushad et al. (2022), a complete genome sequences (MinION and MiSeq) of three *Listeria monocytogenes* strain (GTAL407, GTA L409, and GTAL411) isolated from three different samples of microgreens was sequenced. Researchers will further utilize this genomic data for searching candidate genes associated with microbial resistance gene. As per the report of Alrifai et al. (2021), a semi-targeted metabolomics technique has been performed for the profiling of intact-glucosinolates (GLS) in *Brassica* microgreens by using LC- HRMS/MS. The whole genome sequencing (Illumina NextSeq 500) was performed to characterized the bacterium specie(s) and resistance related genes in isolates obtained from the microgreens (Moon et al., 2022). In addition, shotgun metagenomic sequencing technique has been used to examine the micro-biome and resistome profiles was also carried out. Various analytic techniques for the quantification of primary and secondary metabolites in microgreens was reviewed by Le et al., 2020. Fingerprinting and metabolomic approaches showed great potential in differentiation of the origins, grow conditions, species and cultivars, and storage conditions of food and botanicals. Ultra-high-performance liquid chromatography-high resolution mass spectrometry (UHPLC-PDA-ESI/HRMS/MS) analytical system was used for the metabolomic analysis in $cacl_2$ treated Broccoli microgreen (Sun et al., 2020). The flow-injection mass spectrometric fingerprinting (FIMS), and UHPLC- HRMS based metabolomic methods were used for food/botanical quality evaluation and authentication. In comparison with FIMS, UHPLC-HRMS based metabolomics can give a better understanding of the whole metabolome and then target the components which are responsible for the group differences. The gleams of next-generation microgreens, their genetic enhancement has been recently reviewed by Sharma et al. (2022). Further utilization of omics data, scientist can engineer or edit the genome of microgreens for the improvement of commercial important trait (Fig. 6).

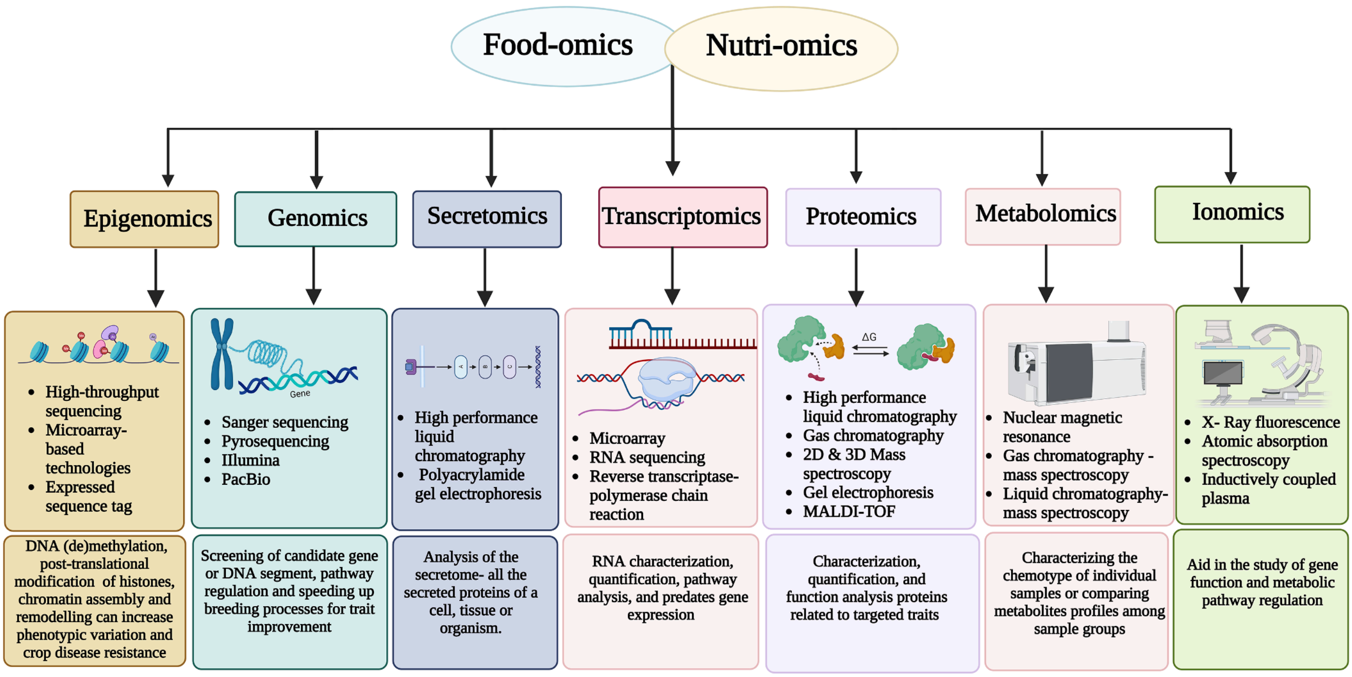

Fig. 5. Highlighting different omic approaches used under food-omics or nutri-omics for the study of DNA, RNA, and amino acid sequencing, metabolites analysis, biosynthetic pathways study in microgreens particularly considering growth and nutrimental prospect. The images were made using BioRender software (https://www.biorender.com/).

10. Potential utility of microgreens

Functional foods, usually referred to as nutraceuticals, are nutrient-dense and associated with numerous significant health benefits. For instance, microgreens have been identified as potential new sources of bioactive chemicals, minerals, and nutrients for use in the formulation of staple foods (Teng et al., 2021). Pea/lupin microgreens have been reported as suitable natural ingredients for bread with quercetin/genistein content. As a result, traditional foods enriched with microgreens could provide suplementary valuable metabolites and meet the specific health necessities of customers. Choe et al. (2018) examined the role of microgreens as functional foods in diet-based disease prevention, namely for the prevention of obesity, cardio-vascular diseases, diabetes, and cancer. Huang et al. (2016) discovered that diet supplementation with red cabbage microgreens improved the health of mice on a high-fat diet.

Microgreens have also piqued the interest of space agencies, which expect that their sensory properties can help to the nourishment of astronauts in microgravity (Teng et al., 2022). Also, microgreen cultivation could contribute to the maintenance of crew physical and mental health on long-duration spaceflight missions. Also, microgreens have ability to regenerate oxygen, fix nitrogen, and offer important nutrients and fresh ingredients (Kyriacou et al., 2017). For space exploration, microgreens are ideally suited due to their limited space and feeding, growth medium needs, as well as their short growing period. As a result of microgravity, growing food in space could face various challenges including seeds germination, watering, root anchoring, and limited resources. Padgett (2018), describes the production and evaluation of films used to secure and hold seeds during the growth process in microgravity. Vanderbrink and Kiss (2017), also hypothesized that plant epigenetic and gene expression mechanisms of plants could be altered by microgravity.

11. Conclusion: challenges, possible solution, and future prospects

Like any emerging field, microgreen production faces its own set of challenges and has future directions for improvement. Here are some key challenges and future directions in microgreen cultivation (Galieni et al., 2020). Microgreen cultivation lacks standardized practices and quality control measures. There is a need to establish industry-wide standards for seed selection, growing media, lighting, temperature, humidity, and nutrient management. Consistent quality control will ensure uniformity in flavor, texture, and nutritional content (Zhang et al., 2021). Microgreens are susceptible to various diseases and pests, such as damping-off, powdery mildew, and aphids (Anonymus, 2023). As microgreens are grown in a high-humid environment, the risk of disease and pest outbreaks is amplified. Developing sustainable and organic methods for disease and pest management will be crucial to minimize crop losses and maintain product quality. Microgreens are known for their high nutritional density. However, research is needed to optimize nutrient levels and ratios to maximize their nutritional value. Understanding the impact of different growing conditions and nutrient formulations on microgreen composition will help growers produce nutrient-rich varieties. Microgreens are typically grown in indoor environments, which require a significant amount of water and energy for lighting and climate control. Addressing the sustainability aspects of microgreen production, such as reducing water consumption and optimizing energy efficiency, will be crucial for long-term viability and environmental impact. Microgreens have a short shelf-life due to their delicate nature and high respiration rates. Improving post-harvest handling techniques, including packaging, storage, and transportation, will help extend their shelf-life and preserve their quality for consumers. Currently, the most commonly grown microgreens include varieties like sunflower, pea shoots, radish, and broccoli (Marchioni et al., 2021). Exploring new crops and introducing a wider variety of microgreens will provide consumers with more options and flavors, and expand the market potential for growers. Many consumers are still unfamiliar with microgreens and their benefits. Increasing awareness and educating consumers about the nutritional value, culinary uses, and sustainability aspects of microgreens will help drive demand and market growth. Automation and technology can play a significant role in optimizing microgreen production. Implementing advanced sensing technologies, automated irrigation systems, and robotic harvesting methods can

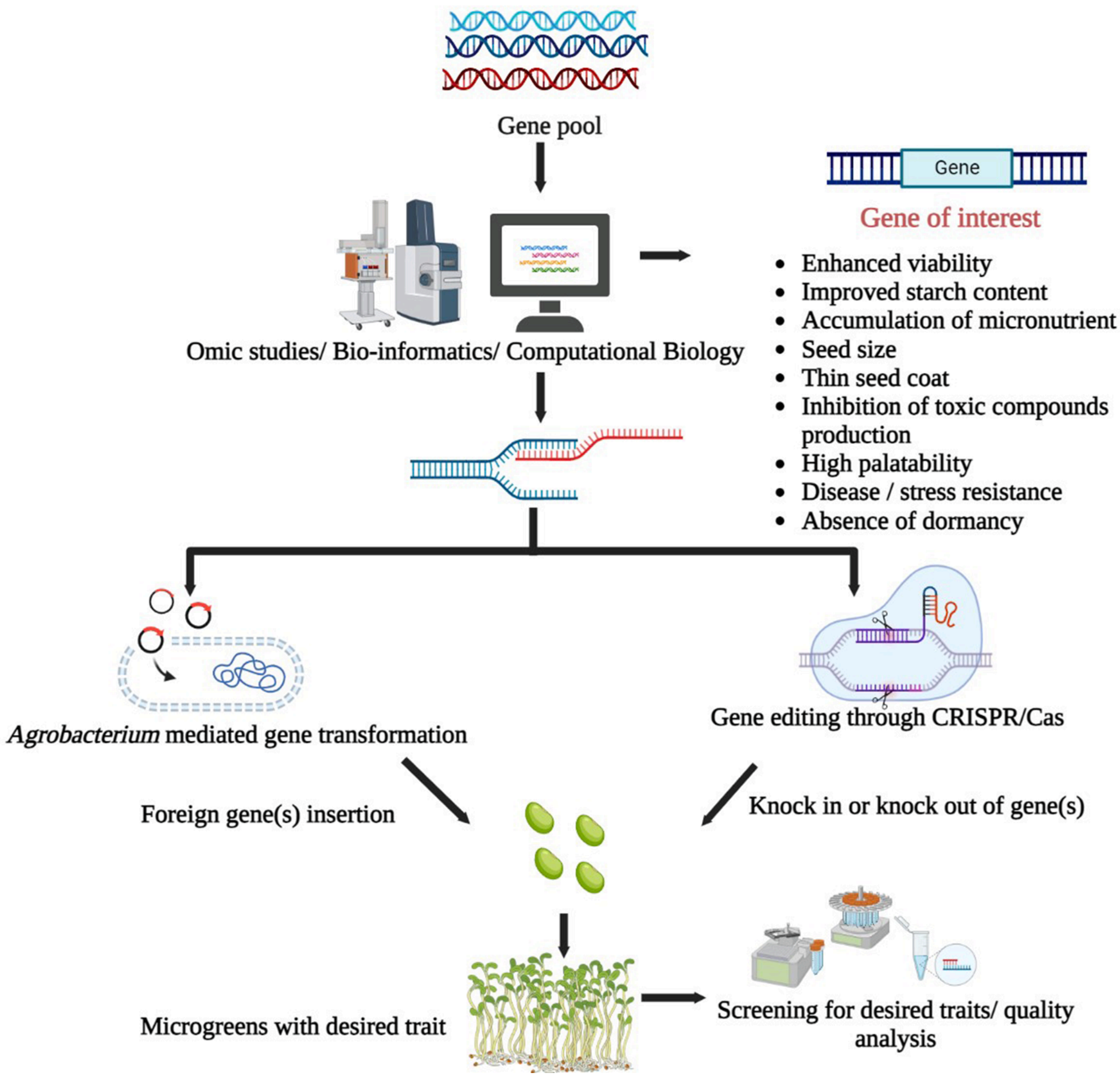

Fig. 6. Flow diagram representing the biotechnological way for the improvement of vital traits in microgreen crops. Firstly, to find the gene of interest from the gene pool using omics and bioinformatics approaches. Afterward, the desired gene is transferred to targeted plant using transformation or edited by gene editing approaches. The images were made using BioRender software (https://www.biorender.com/).

improve efficiency, reduce labor costs, and ensure consistent quality. Microgreens are well-suited for vertical farming and urban agriculture due to their compact size and rapid growth cycle. Embracing these methods can help maximize space utilization, reduce transportation costs, and bring microgreens closer to urban consumers. Continued research and innovation are vital for the future of microgreen cultivation. This includes exploring novel growing techniques, developing new cultivars with enhanced flavors and nutritional profiles, and investigating the potential therapeutic applications of microgreens. Overall, addressing these challenges and focusing on future directions will contribute to the sustainable growth and widespread adoption of microgreens as a nutritious and flavorful food option. Biotechnology can play an important role to overcome the problem associated with infection, pre/post-harvest, quality, and shelf life. But to date, very limited research has been conducted on biotechnological perspective in microgreens. Further utilizing omics technology, genetic engineering, and gene editing approaches could be beneficial for enhances consumer preferred traits in microgreen.

Compliance with ethics requirements

This article does not contain any studies with human or animal subjects.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CRediT authorship contribution statement

Mahinder Partap: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Diksha Sharma:** Formal analysis, Methodology, Writing – original draft. **Deekshith HN:** Formal analysis, Methodology, Writing – original draft. **Meenakshi Thakur:** Formal analysis, Visualization, Writing – original draft. **Vipasha Verma:** Writing – original draft, Writing – review & editing, Data curation. **Ujala:** Writing – original draft. **Bhavya Bhargava:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition, Resources, Supervision.

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Data availability

No data was used for the research described in the article.

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