Chapter 5
Microgreens: A Future Super Food

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Abstract Leafy greens are nutrient-packed leaves of herbs, shrubs, or trees, consumed along with tender petioles and shoots as vegetables and complete a balanced diet. They are high in dietary fiber, eaten raw or cooked, and appreciated for their bland to tangy taste. The leafy greens of herbaceous plants, more so in the recent past, are being marketed in the form of microgreens. The microgreens are miniature seedlings of herbs, very tender, crunchy, fresh, and fragrant. Moreover, they are highly nutritional compared to mature leafy greens. Microgreens contain a considerably higher concentration of vitamins and carotenoids than mature plants, but the type and quantity differ among the microgreens originating from the different plant types. The current chapter focuses on the different aspects that should be considered while growing microgreens, as well as the information about seeds that are suitable to be raised as microgreens. Also, there is an account of the growth media, light, temperature, nutrient requirements, and other methods that may be adopted to cultivate microgreens either at home or on small-scale commercial farms. Preliminary studies have irrevocably proved the nutritional and health benefits offered by microgreens, and so the recent findings in this area are updated for the interested readers. Microgreens have a short growth period, and there is every chance that they will be contaminated during harvest, storage, and transport. Therefore, awareness about the necessity of axenic conditions for microgreen cultivation is also provided. Many pre and postharvest practices may be adopted to obtain fresh and healthy produce. This would enable us to bring variety to our food palette. Thus, it is clearly evident that if proper care is taken, microgreens can become a future food choice. Hopefully, we will be able to witness the impending microgreen revolution.

Keywords Microgreen · Leafy green · Vitamin-rich food · Super food

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5.1 Introduction

Green leafy vegetables are considered to be rich sources of several vital nutrients (Kamble and Jadhav 2013). The diversity of leafy greens and their usage varies widely both with respect to the geographical area and cultural affiliations of the residents (Welbaum 2015). Among the known leafy crops worldwide (~50,000), only a very limited (~1000) number is commonly used as vegetables. It is estimated that in India, only about 125 plant species are consumed as edible greens (Bandopadhyay and Mukherjee 2009). However, it should be understood that there are many more potential leafy edibles. Many lesser-known, underutilized leafy greens can be utilized for nourishing the ever-increasing human population due to their promising nutritive value, diversity in taste, and fragrance (Sheela et al. 2004). Underutilized plant resources are the foundation of diversity in developing nation societies, ancient, and autochthonous food systems (Sahoo et al. 2021).

Botanically, leafy greens are defined as young, edible, active growth-phased plants with fresh leaves. The leaves are usually consumed along with tender petiole and shoot. They are mostly short-lived and rapidly growing plants with herbaceous nature. They are marketed within a short period of time (Sahu et al. 2020). The leafy greens are blessed with an array of bioactive compounds, including antioxidants, vitamins, and minerals, also called nature's anti-aging wonders. They are low in carbohydrates but rich in folic acid and dietary fiber content. The nutritional value of these underutilized greens is 20 times more than in other market vegetables (Sudha and Mathanghi 2012). Cultivating these greens will be a great way to increase food production and ensure balanced nutrition, food security, health security, and poverty alleviation in the deprived sections of society (Buragohain et al. 2013).

5.2 Microgreens

Leafy greens may be consumed as miniature forms, also referred to as the 'microgreens.' Microgreens have gained acceptance in society in very recent times for almost a decade or so (Bulgari et al. 2021; Turner et al. 2020). Consequently, several leafy greens are being marketed as microgreens, which are smaller, very tender, and more nutritional (in terms of vitamins and minerals) than mature leafy greens.

Microgreens are described as young and tender edible seedlings with fully developed cotyledonary leaves along with the emerging first true leaves. Microgreens are commonly termed as 'Vegetable Confetti,' portrayed as soft juvenile greens raised from the seeds of grains, vegetables, or herbs (Sharma et al. 2020). They have three basic parts: a central stem, cotyledon leaves, and typically the first pair of true leaves. The size of the harvested microgreens may vary depending upon the specific plant type. When the greens grow beyond the above-mentioned size, they are called petite greens. The seeds of a wide variety of herbs (e.g., basil and cilantro), vegetables (e.g., radish, broccoli), and even flowers (e.g., sunflower) are grown as microgreens.

Microgreens are primarily used in the restaurant industry to embellish the cuisine and are most commonly consumed fresh in salads, soups, and sandwiches. Traditionally only a very few plant varieties are offered as microgreens, such as Argula, Basil, Beets, Kale, and Cilantro in the South East Asian countries (Xiao et al. 2012). Today, it is getting more popular, and in the US, there is a boom in the microgreen industry as a variety of seed companies and growers are involved in the growing and marketing of microgreens. These are also provided as a mixture called Rainbow Mix. Mustard cress, Radish green, Spinach, Basil, Coriander, Fennel, Argula, Beet greens, and Kale microgreens are commonly available in the markets (Fig. 5.1). Scientific data on the nutritional contents of microgreens are limited. Still, research has shown that microgreens contain high concentrations of many nutrients when compared with mature, fully grown vegetables or herbs. Data on nutrients such as carbohydrates and proteins are scarce. However, several studies have demonstrated the high level of phytonutrients, antioxidants, vitamins, and minerals that the microgreens contain (Xiao et al. 2012).

Microgreens are considered potential functional foods with nutritional benefits and health improving or ailment prevention characteristics. Microgreens contain a considerably higher concentration of vitamins and carotenoids than mature plants; however, they differ in the type of plant. The maximum value of vitamins C, E, and K was seen in red cabbages, garnet amaranth, and green daikon radish compared to many others studied (Xiao et al. 2012). Cilantro microgreens showed the highest concentrations of lutein, zeaxanthin, violaxanthin, and beta-carotene, but Popcorn or Maize shoots and golden pea tendrils have relatively low vitamins carotenoids compared to their mature forms (Xiao et al. 2012). All the vitamins and carotenoids are usually concentrated in the cotyledon leaves. The macro and micro-minerals were found to be high in almost all microgreens. However, the mineral content varied according to the growth media used for culturing them. The mineral concentration of compost-grown broccoli microgreens had higher amounts of P, K, Mg, Mn, Zn, Fe, Ca, Na, and Cu than the others, while the hydroponic cultures showed larger quantities of Mg, Mn, Cu, and Zn compared to control (Weber 2017). Microgreens are valuable nutritional supplements to the human diet. Therefore, microgreens should be produced sufficient to ensure availability to all.

Light exposure during the sprouting, growing, and storing period had an effect on quality. For example, light exposure during storage had an effect on the phenolic and alpha-tocopherol content. It also increases the amount of ascorbic acid. Dark storage results in higher hydroxyl radical scavenging capacity and carotenoids retention, i.e., light exposure accelerates the deterioration of radish microgreens, while dark storage maintains quality (Xiao et al. 2014). Golden pea tendrils, which were grown in the absence of light, showed much lower vitamin and carotenoid content. Hence, it appears that light plays a vital role in nutritional value (Xiao et al. 2012).

They are attractive with their colors, textures, and flavors. Microgreens can be grown and harvested within 7–14 days after germination in a very simple way; hence, they are considered suitable for urban agriculture (Renna and Paradiso 2020).

Fig. 5.1 Microgreens of local vegetables in India

Microgreens are also ideal for indoor production and controlled environmental agriculture. Short harvest time heightens its market values and categorizes them as important Controlled Environment Agriculture crops (Wood 2019).

Although interest in microgreens has expanded, the main market clients continue to be restaurant chefs as well as health food store owners. The most likely successful marketing strategy for producers interested in growing microgreens is to work in association with a restaurateur or chef, growing and delivering microgreens at their requests and preferences. Microgreens are typically purchased and used by restaurants in small amounts, and the quick growing and harvest time may make this a more attractive crop for very small growers interested in developing nearby, high-end specialty markets for fresh produce. Even though microgreens are super greens, they face many challenges in markets due to their speedy degradation and short storage life.

However, as the microgreens perish fast, they should be washed, stored properly, and subjected to good handling practices. They can create substantial marketing challenges, particularly for inexperienced growers. Due to these difficulties, they are usually cultivated in small batches on specialized farms. There are innumerable websites dedicated to microgreen cultivation protocols (https://www.allthatgrows.in/collections/micro-greens-seeds). It appears that many people have taken up microgreen farming as a serious profession as the demand for these rises around the world. Supermarkets are now stocking them in small fresh batches. These baby greens are valued and popular as they are entirely organic and also as they are nutritional and crunchy, and their display looks wonderful on a dish.

5.3 Plant Seeds Used for Microgreen Cultivation

Microgreens can be produced from the seeds of many vegetables, herbs, and agronomic crops. Microgreens are cultivated in a variety of environments, specifically indoor, outdoor, and controlled environments, i.e., greenhouse and developing frameworks (growing systems) that is either containing soil or soilless substrate, depending on the scale of production. Containerized production, adaptable both to micro-scale urban and large-scale commercial operations, allows for the commercialization of the product while growing on the media, to be harvested directly by the end-user (Bhatt and Sharma 2018).

Microgreens are often marketed as specialty mixes and tagged with adjectives such as ‘sweet,’ ‘mild,’ ‘colourful,’ or ‘spicy.’ Crops like lettuces are not usually used as microgreens because they are too delicate and wilt easily. Growers should evaluate various crop varieties to determine their value as microgreens. The kinds of crops that are selected for production and sale as microgreens have value in terms of color, unique textures, or distinct flavors. Certain crops, including cabbage, beet, kale, kohlrabi, mizuna, mustard, radish, swiss chard, and amaranth of microgreens, germinate easily and grow quickly. Soaking of seeds prior to sowing helps facilitate germination.

Almost 80–100 crop varieties are used as microgreens. According to Parida (2020), seeds of Anise, Basil, Beet, Cabbage, Carrot, Cauliflower, Celery, Cucumber, Chickpea, Coriander, Corn, Dwarf copperleaf, Edible amaranth, Fennel, Fenugreek, Finger millet, Flax, Foxtail millet, Great Millet, Green gram, Green amaranth, Lemongrass, Little millet, Marigold, Mint, Mustard, Oats, Onion, Pea shoots, Pearl millet, Pendant amaranth, Pigweed, Pumpkin, Purple amaranth, Radish, Sesame, Spinach, Spiny amaranth, Sunflower, Turnip, and Wheatgrass can be used for innovative farming at home. Most commonly, seeds used for microgreen cultivation include carrot, cress, arugula, basil, onion, chive, broccoli, fennel, lemongrass, popcorn, buckwheat, spinach, sweet pea, and celery. Prices for microgreens generally range from \$30 to \$50 per pound. The product is packed in plastic clamshell containers that are typically 4–8 oz. by weight but can be sold in 1 lb. containers as well (Treadwell et al. 2020).

5.4 Mode of Cultivation of Microgreens

Growing small quantities of microgreens at home is very easy, but growing and marketing high-quality microgreens commercially are a bit difficult. Commercial growers should select crops that have a similar growth rate so that the produce from each growth tray can be harvested at once. Alternatively, growers can seed the various crops singularly and mix them after harvest (Treadwell et al. 2020).

Cultivation of microgreens is a simple process that does not require much time, energy, and experience (Franks and Richardson 2009). However, little care should be needed in each step, and further research is required to improve productivity, nutritional quality, and the cost of production. Even if microgreens' life cycle is very short, seed germination velocity should be improved to determine a more rapid stabilization and to promote vigorous seedlings (Delian et al. 2015). Microgreen production depends on factors such as water, substrate, and energy intake. Energy consumption mainly depends on the lighting since the optimization of light emission in terms of quality and intensity can improve the system's sustainability. The effect of substrates such as vermiculite, coconut fiber, and jute fabric was tested on microgreens' production and quality traits to identify the best cultivation conditions (Bulgari et al. 2021).

Indigenous landraces, underutilized crops, and wild-edible plants constitute a vast repository for the selection of genetic material for microgreens. Microgreens can be grown in single-planting flat containers, mats, or lining. The substrata should be placed in the bottom of a tray or longer trough using standard, sterile, loose, soilless germinating media, including peat, vermiculite, perlite, coconut fiber, or any others. The substrata should be filled in a tray, and irrigation programs should be devised accordingly. Overhead mist irrigation is used only through the germination stage in these media systems.

According to Gayathree et al. (2019), seed germination of most of the species was >75%, with the time taken to reach 75% germination within 14 days. Lettuce and carrot were found to be the most preferred microgreens, followed by peas and amaranth. Poor germination can be attributed to unfavorable temperature, quality and quantity of light, lack of moisture, and inherent factors. After germination, trays should be sub-irrigated to avoid excess moisture in the plant canopy. Seeding density is difficult to recommend. Most growers want to grow microgreens as densely as possible to maximize production. However, it should be noted that when dense, crowding leads to elongation of stems and increases the risk of diseases (Treadwell et al. 2020).

Pre-sowing treatments are good for standardizing and shorten the production cycle. Seed surface sterilization with non-chemical treatments having antimicrobial action is more effective for yielding healthy greens. Crop-specific information on sowing rate along with details on its yield and quality need further attention (Kyriacou et al. 2016). Modular light exposure may fortify the bioactive content of microgreens and augment their sensorial attributes. Most crops require little or no fertilizer because the seed provides adequate nutrition for the young crop. Some longer-growing microgreen crops, such as micro-carrot, dill, and celery, may benefit from light exposure applied to the tray bottom. Some of the faster-growing greens, such as mustard cress and chard, may also benefit from the light because they germinate quickly and exhaust their self-contained nutrient supply quickly. Light exposure is best achieved by floating each tray of microgreens for 30 s in a prepared nutrient solution of approximately 80 ppm nitrogen (Treadwell et al. 2020).

Microgreens are smaller than baby greens and larger than sprouts; therefore, their harvesting stages are also in between those two stages; hence, special attention is required (Xiao et al. 2012; Ebert 2013). Harvesting at the right stage is an important production strategy as it varies greatly from crop to crop. Some growers cultivate mixed crops of microgreens having similar growth rates so that the whole crops can be harvested at once (Bhatt and Sharma 2018).

It is mostly recommended that seedling height should be the harvested index due to its easiness in determination. However, the leaf area can also be used as a harvesting stage index (Gayathree et al. 2019). Microgreens are ready for harvest when they reach the first true leaf stage, usually at about two in. tall. The time from seeding to harvest can vary greatly by crop, from 7 to 21 days. Production in small trays will likely require harvesting with scissors. This is a very time-consuming part of the production cycle and is often mentioned by growers as a major drawback. The seeding mat type of production system has gained popularity with many growers because it facilitates faster harvesting. The mats can be picked up by hand and held vertically while an electric knife or trimmer is used for harvesting, allowing cut microgreens to fall from the mat into a clean harvest container.

Harvested microgreens are highly perishable and immediately washed and cooled as soon as possible, using good handling practices for food safety (Treadwell et al. 2020). Microgreens are generally packed in polyethylene packages and cooled to recommended temperatures before supplying to the market or consumers (Bhatt and Sharma 2018). To improve quality, some chefs ask growers to deliver microgreens in the trays or mats so that they can cut the microgreens as needed.

Pre and postharvest select-waveband, intensity, and photoperiod combinations can elicit compound-specific improvements in functional quality and in shelf life. Research is needed to identify effective sanitization and drying methods (do not compromise on quality) and shelf life for the commercialization of ready-to-eat packaged microgreens. Genotypic variability in postharvest chilling sensitivity and the interactions of temperature, light conditions, and packaging gas permeability should be further examined to establish environments that are suppressive on respiration but preventive of off-odor development (Kyriacou et al. 2016). Aloe vera gel spray coating was suggested as an eco-friendly ergonomic preharvest treatment along with PET–CS for the enhancement of postharvest quality and shelf life in radish and rosella microgreens, with a high potential to be extended to other microgreens.

Scientists have explored the preharvest and postharvest interventions, such as calcium treatments, modified atmosphere packaging, temperature control, and light, to maintain quality, augment nutritional value, and extend shelf life. However, more research is to be conducted to optimize production and storage conditions to improve safety and quality and increase the shelf life of microgreens, thereby expanding their potential markets (Turner et al. 2020).

5.5 Nutritional Composition and Health Benefits of Microgreens

Microgreens are miniature greens that can be recommended as nutraceuticals and functional foods due to their health-promoting and disease-preventing properties and their nutritional value. It is obvious that microgreens are good sources of phytonutrients. Nowadays, microgreens are becoming the emerging alternative to fortified and genetically modified food, as it provides a sufficient amount of nutrition. Microgreens are low in fat, calories, and antinutrients but rich in moisture content, vitamins, carotenoids, and other phytochemicals. The microgreens were found to be moderate to good sources of protein, dietary fiber, and essential elements. They are excellent sources of ascorbic acid, Vitamin E, and beta-carotene (provitamin A) (Ghoora et al. 2020). Microgreens may have 4–40 times the amount of some nutrients and vitamins as the vegetables a mature plant would produce (Weber 2017).

During seed germination, biochemical changes within the seeds lead to the activation of various enzymes, which in turn result in the degradation of macromolecules into micro-molecules that the body can absorb easily. These changes result in the rapid elevation of the amount of bioactive constituents such as vitamins and antioxidants that are easily absorbable and are beneficial to the human body (Kowitcharoen et al. 2021). Thiamine, riboflavin, and niacin were high in microgreens of *Amaranthusviridis, Vignaradiata,* and *Allium cepa*, respectively. However, vitamin content was higher in sprouts than in microgreens and mature edible parts of selected plants, even though some exceptions were found. Antinutrients analyzed in microgreens were below the toxic levels. Microgreens have low carbohydrates and antinutrient contents; but high vitamin contents, so these can be recommended as a dietary supplement, especially for those who prefer less carbohydrate-containing food supplements (Nair and Lekshmi 2019). According to Xiao (2013), among the 25 microgreens assayed, red cabbage, cilantro, garnet amaranth, and green daikon radish had the highest concentrations of ascorbic acids, carotenoids, phylloquinone, and tocopherols, respectively when compared to the nutrient concentrations in mature leaves recorded in USDA National Nutrient Database, microgreens possessed higher nutrient density.

Research has shown that microgreens possess antioxidants and a number of polyphenols in contrast to their fully grown vegetable counterparts (Xiao et al. 2019). Microgreens of mung beans and lentils had higher carbohydrate and protein contents than others. Lentil microgreens had the highest total chlorophyll, carotenoid, and ascorbic acid contents. Buckwheat microgreens showed the highest total phenol content (TPC) and maximum DPPH scavenging activity. Red cabbage has a higher anthocyanin content than purple radish (Kowitcharoen et al. 2021). The highest concentration of vitamin C, carotenoids, phylloquinone, and tocopherols was found in red cabbage, cilantro, garnet amaranth, and green daikon radish. The study concluded that microgreen cotyledon leaves possess higher nutritional value than mature leaves. Researchers also found about five times greater vitamins in microgreens than in their mature plant counterparts (Xiao et al. 2012). Broccoli and cauliflower microgreens had higher concentrations of carotenoid contents than mature florets (Xiao et al. 2019). Niroula et al. (2019) found that carotenoid content increased in wheat and barley microgreens over the course of the 16-day growth period studied.

The concentration of bioactive compounds from microgreens of wheat, lentils, radishes, and sunflowers showed that they had richer saturated fatty acids (palmitic acid) than unsaturated fatty acids, whereas alfalfa microgreens have significantly higher amounts of unsaturated fatty acids (oleic and linoleic acids) than other microgreens. For radish sprouts, it was noticed that the content of glucosinolates increased after germination. Glucosinolates are beneficial against human cancers. The studies evaluated that microgreens are nutritionally superior to sprouts in terms of polyamine content. Alfalfa microgreens showed the highest levels of agmatine, lentil microgreens had the highest content of spermidine, while fenugreek microgreens showed the highest content of spermine. Moreover, the nutritionally beneficial polyamines (agmatine, spermidine, and spermine) were accumulated in microgreens and a lower cadaverine content (Renna and Paradiso 2020). There was a substantial increase in vitamin C content from amaranth sprouts to microgreens (2.7-fold). Both provitamins A, α-carotene, and β-carotene were considerably increased from sprouts to microgreens. The content of α-carotene was the same at the microgreen and fully developed stage (Kyriacou et al. 2016). Brassicaceae microgreens are good sources of macroelements (e.g., potassium and calcium) and microelements (e.g., iron and zinc) (Xiao et al. 2016). Ebert et al. (2014) reported that fully grown *Amaranthus tricolor* showed higher protein, iron, vitamin c, b-carotene, lutein, and violaxanthin contents than sprouts and microgreens. Microgreens had a higher content of α-carotene, βcarotene, violaxanthin, lutein, and neoxanthin than sprouts.

According to Sun et al. (2013), who profiled the polyphenols in five microgreen cultivars of the genus Brassica, there were about 165 phenolic compounds comprising many highly glycosylated acylated quercetin, kaempferol, cyanidin glycones, and complex hydroxycinnamic and benzoic acids. They reported more complex polyphenol profiles and a greater variety of polyphenols in the microgreens than in their mature plant counterparts. The protective effect against the oxidative stress shown by Brassicaceae (broccoli, Brussels sprouts, cabbage, kale, and cauliflower) is given by glucosinolates which are sulfur-containing glucosides. For example, in broccoli, there are sinigrin, glucoraphanin, and progoitrin; in Chinese cabbage, there is indolyl glucosinolate gluco brassicin and glucoraphanin (one of the most abundant glucosinolates present in broccoli).

Lettuce contains various health-promoting phytochemicals, including vitamins and phenolic compounds with antioxidant properties. Oh et al. (2010) found that young lettuce (*Lactucasativa*) seedlings, after 7 days of germination, had the highest total phenolic concentration and antioxidant capacity in comparison to the mature leaves.

Regardless of how they were grown, microgreens had larger quantities of Mg, Mn, Cu, and Zn than vegetables. However, compost-grown (C) microgreens had higher P, K, Mg, Mn, Zn, Fe, Ca, Na, and Cu concentrations than the vegetables (Weber 2017). Analysis of microgreens of *Brassica* revealed that they are excellent sources of the macroelements, K and Ca, and the microelements, Fe and Zn (Xiao et al. 2016). Additionally, they were found to be moderate to excellent sources of ascorbic acid, phylloquinone, carotenoids, tocopherols, glucosinolates, and polyphenols (Xiao et al. 2019). Cauliflower, rapini, red radish, China rose radish, and ruby radish microgreens were found to have the greatest contents of total ascorbic acid, phylloquinone, total tocopherols, total glucosinolates, and TPC, respectively. Ruby radish microgreens also had the greatest DPPH radical scavenging capacity. Radish and mustard were found to have the highest bioaccessible fraction (BF) for ascorbic acid, total carotenoids, and total isothiocyanates, while broccoli, kale, and radish all had comparable high BF (Body Fat) or total polyphenols. Broccoli and mustard showed the lowest and highest BF values, respectively, for potassium and magnesium, while kale had the highest BF value for calcium (de la Fuente et al. 2019). Pinto et al. (2015) showed that microgreen lettuce (*Latucasativa* var. *capitata*; 2 week old) had a higher content of most minerals (Ca, Mg, Fe, Mn, Zn, Se, and Mo) than mature lettuce (10 week old). Kyriacou et al. (2019) reported that basil and swiss chard microgreens were good sources of K and Mg, and purple basil was high in ascorbic acid, while green basil and coriander were especially excellent sources of beta-carotene and total polyphenols. Lupin microgreen bread retained high levels of genistein which has anticarcinogenic properties, especially in women (Romognolo et al. 2017). Polash et al. (2018) demonstrated that bioactive components and antioxidant activity in mustard, radish, and cabbage microgreens degraded rapidly after harvest so that to obtain substantial health benefits from eating microgreens, they should be consumed soon after harvest. Microgreens possess a higher content of most minerals (Ca, Mg, Fe, Mn, Zn, Se, and Mo) and a lower NO_3^- content than mature lettuces. Therefore, microgreens can be considered a good source of minerals in the human diet, and their consumption could be an important strategy to meet children's dietary mineral requirements without exposing them to harmful NO_3^- (Pinto et al. 2015). The wild greens (*Sanguisorba minor* Scop, *Sinapis arvensis* L., and *Taraxacum officinale* Weber ex F. H. Wigg.) showed high amounts of Mg, P, Zn, Mn, Mo, and Fe content. However, the wild greens also showed high amounts of nitrate and traces of some metals, potentially detrimental to health. This cautions against the use of wild species for producing microgreens and baby leaves (Lenzi et al. 2019). Studies indicated that the nutrient data of Brassicaceae microgreens could be valuable to dieticians, nutrition policymakers, health-conscious consumers, and growers in the selection of nutrient-dense vegetables. For instance, reports state that broccoli microgreens have higher contents of bioactive compounds and potent antioxidants and exhibit higher anti-inflammatory and anticancer activities than their corresponding mature plants (Kowitcharoen et al. 2021).

In addition to their high nutritional value, microgreens are considered functional foods with particular health-promoting or disease-preventing properties. Sprouts and microgreens can be easily produced in urban or peri-urban settings where land is often a limiting factor, by either specialized vegetable farmers or the consumers themselves. Sprouts and microgreens can be grown without soil and without external inputs like fertilizers and pesticides, around or inside residential areas considering their short growth cycle. Moreover, sprouts and microgreens are usually consumed raw; hence, there is no loss or degradation of micronutrients through food processing.

Microgreens are gaining increasing popularity as an innovative horticultural product. Six microgreen species were evaluated by researchers: Dijon mustard (*Brassica juncea* L. Czern.), opal basil (*Ocimum basilicum* L.), bull's blood beet (*Beta vulgaris* L.), red amaranth (*Amaranthus tricolor* L.), peppercress (*Lepidium bonariense* L.), and China rose radish (*Raphanus sativus*L.). They found a strong correlation between the total phenolic content of the microgreens and their flavor attributes. The chemical analysis revealed that China rose radish, opal basil, and red amaranth have the highest concentrations of total ascorbic acid, phylloquinone, carotenoids, and tocopherols, while the highest concentrations of total phenolics were found in China rose radish and opal basil. The study also concluded that microgreen growers could use pH and total phenolic values as indicators and predictors of consumer acceptability. Unfortunately, the study results reflected the reality that people reject some vegetables because of their unpleasant flavor (bitterness, astringency), even if they have a beneficial effect on human health (Stoleru et al. 2016).

Microgreens play a vital role in health-promoting diets. Microgreens are a nutrient-rich food that contains more digestible vitamins, minerals, and other phytonutrients than the corresponding mature plants. They are excellent sources of nutritional and bioactive compounds, hence, having the potential for the prevention of malnutrition and chronic diseases (Teng et al. 2021). In a comparative study of fresh microgreen and radish vegetables, the concentration of five minerals, i.e., F, Mg, K, Ca, and total phosphorous, vitamin B9, vitamin C, and Omega 3 fatty acid concentration are 1–3 times higher than the fresh radish (Rani et al. 2018).

Microgreens of *Brassica oleracea* L. var. *italica* have a substantial amount of bioactive constituents, including glucosinolates, phenolic compounds, vitamins, and essential minerals. These secondary metabolites are positively associated with health benefits. In vitro and in vivo studies demonstrated that broccoli seedlings possess various biological properties, including antioxidant, anticancer, antimicrobial, anti-inflammatory, antiobesity, and antidiabetic activities. Hence, it can serve as a potential reference for food selections of consumers and applications in functional food and nutraceutical industries (Le et al. 2020).

Both in vitro and in vivo studies showed that microgreens can act as the best functional food with potential benefits to human health because of their anti-inflammatory, anticancer, antibacterial, and antihyperglycemia properties, prevention, and treatment of chronic diseases (Zhang et al. 2021). According to Huang et al. (2016), red cabbage microgreen lowered the weight gain induced by high-fat diet and reduced circulating LDL levels and expression of hepatic inflammatory cytokines in mice fed a high-fat diet. This is probably due to the effect of polyphenol contents in red cabbage microgreens with antioxidant and anti-inflammation properties.

Chlorophyll and Carotenoids contents in the cereal microgreens correlate with its health-promoting components like phenolics and antioxidants, play a role against clinical conditions like thalassemia and hemolytic anemia, and reduce the risk of some chronic diseases, such as cancer, cardiovascular diseases, skin diseases, and age-related eye diseases (Niroula et al. 2019).

According to Tan et al. (2020), the soil-grown farm broccoli microgreens possessed a significantly higher vitamin C content than hydroponically grown and commercial microgreens. The farm grown broccoli microgreens possessed much higher chlorophyll content and total phenolic content as compared to many species of mature vegetables. Regardless of the growing method or environment, microgreens have the potential to serve as functional foods. Microgreen supplementation has the ability to lower circulating LDL levels in animals fed with a high-fat diet and reduce hepatic cholesterol ester, triacylglycerol levels, and expression of inflammatory cytokines in the liver. Microgreens of red cabbages can modulate weight gain and cholesterol metabolism and may protect against CVD by preventing hypercholesterolemia (Huang et al. 2016). According to Di Gioia et al. (2019), Brassicaceae species grown in soilless systems are good targets for producing high-quality Zn and Fe-biofortified microgreens by simply manipulating nutrient solution composition.

So, in general, we can say that microgreens can be recommended as a functional food to enhance and reduce the dietary-related problems in humans. But elaborate research is required to underline and highlights its health benefits.

5.6 Food Quality of Microgreens and Safety in Consumption

The rapidly developing microgreen industries face many challenges. One major limitation is the rapid quality deterioration of microgreens due to their short shelf life. Once harvested, microgreens quickly dehydrate, wilt, decay, and rapidly lose their tender texture, color, and certain nutrients. Deterioration occurs soon after harvest, restricting to local sale units. Second, there is a chance of carrying foodborne pathogens, and hence, steps should be taken during cultivation and harvest to reduce the pathogen attacks (Turner et al. 2020). Warriner et al. (2003) reported that microgreens are more susceptible to bacterial internalization than mature vegetable plants.

The seed releases a mixture of carbohydrates and peptides that can attract surrounding bacteria in the rhizosphere during seed germination. Bacteria can enter via germinating radicals or secondary roots and can persist in localized sites. In immature plants, protective structures are not fully formed, which enables the entry of bacteria into the xylem, thereby spreading it. For microgreen production, seeds are soaked in water to enhance germination without light, in very high humidity and warm temperatures, often with recirculating water. Any microbial contamination on seeds or production equipment, introduced by insects, or lack of hygienic practices by workers will lead to contamination of the entire batch mainly due to the rapid growth of microbes. Therefore, seeds should be certified, and microgreens should be produced by good agricultural practices. Seed decontamination is another crucial step.

5.7 Best Pre and Postharvest Practices for Microgreens

Microgreens' industrial production and marketing are limited by their short shelf life and quick deterioration in product quality. It raises prices and confines trade to local sales. Microgreens that have been harvested are readily dehydrated, wilt, rot, and lose some nutrients, as well as their soft texture and color. Microgreens' shelf life is now being extended using a variety of pre and postharvest procedures.

Microgreens can have a longer shelf life if they are sold still rooted in the growing medium or if they are picked and kept cool. According to previous research, quality can be maintained for over 14 days (Turner et al. 2020). Berba and Uchanski (2012) suggested that the age of the seedlings influences the shelf life of microgreens at harvest. For example, radish is harvested at 7 days, arugula at 9 days, and red cabbage at 11 days.

Major preharvest factors of microgreen production, such as crop selection, fertilization, biofortification, lighting, and growth stage at harvest, are addressed with respect to crop physiology and quality, as well as postharvest handling and applications, temperature, atmospheric composition, lighting, and packaging technology which influence shelf life and microbial safety (Kyriacou et al. 2016).

The effects of temperature, relative humidity, packing material, and microbial load significantly differ in the shelf life. It is advised that products are stored in the dark at a low temperature throughout distribution and retail. According to Kou et al. (2013), temperatures between 5 and 10 °C with moderately high O_2 (14.0–16.5 kPa) and moderately low CO_2 (1.0–1.5 kPa) conditions can be used to maximize the shelf life of buckwheat microgreens. Likewise, researchers from the USDA-ARS Food Quality Laboratory identified that the usage of film bags with high porosity to oxygen content helps daikon radish microgreens to maintain their nutritional value. The US FDA (1999) recommended that all seeds used for sprout/microgreen production should be treated to reduce the pathogens. Alfalfa and clover seeds are mainly used for sprouting but are not typically grown for microgreens. In contrast, radish and broccoli seeds are widely used for microgreen production. Plants in microgreen production are generally anchored by rooting them in a solid medium. After germination, they are exposed to light and moving air, which causes water evaporation from the growth matrix and reduces humidity. Here, water is not usually recirculated but frequently grown in hydroponic systems. Microgreens are generally harvested by cutting stems above the root at the emergence of the first pair of true leaves and the fully developed cotyledons (Berba and Uchanski 2012). All these are much safer, but care should be needed for proper cutting.

Clean water should be used to reduce the chance of contamination while growing. Riggio et al. (2019) suggested that the interaction of the harvesting implement with the cut edge of the stem may be another source of contamination. Instead of worker handling, mechanization of harvesting can reduce the chance of further contamination of microgreens, or education can improve worker hygiene practices. Studies have demonstrated that microgreens growing in hydroponic systems are vulnerable to pathogen proliferation when seeds are contaminated. Hence, seed sanitation is necessary (Reed et al. 2018; Wright and Holden 2018; Xiao et al. 2015). Overall, microgreens are harvested by cutting the stems and, hence, are highly susceptible to dehydration and quality deterioration. So, refrigeration and proper packaging are essential to maintain their quality (Turner et al. 2020). The US FDA has not defined commodity-specific guidelines for microgreens (Wang 2016).

Microgreens may be washed after harvest to remove soil particles, which reduces the initial bacterial load to provide a clean product for packaging. Washing prior to packaging creates a humid environment which promotes microbial growth. Hence, removal of excess water is essential. Many growers choose not to wash, as the additional handling by washing and dewatering can damage the delicate microgreens, which leads to a greater susceptibility to microbial growth. Removing excess moisture after washing without causing damage is a challenge. Thus, a delicate balance is required to maintain temperature, moisture, and atmosphere that optimize microgreens' quality retention and shelf life while discouraging the growth of spoilage microbes and human pathogens (Turner et al. 2020).

The sensory attributes and overall acceptability and liking of microgreens are primarily influenced by their phytochemical content. Microgreens have become used commonly only in the recent past, and research on microgreens is in its infancy. Studies should optimize the pre and postharvest practices for nutrient enhancement and retention. Therefore, increasing public awareness and acceptance of microgreens may be an important consideration in the promotion of this new functional food to the general population (Zhang et al. 2021).

For the commercialization of ready-to-eat packaged microgreens, more research is needed to identify effective sanitizers and drying methods that are not harmful to quality or shelf life (Kyriacou et al. 2016). The microgreens are usually washed clean postharvest. Improved wash/drying methods should be available for ready-to-eat microgreens with greater quality and shelf life. The postharvest wash phase can be avoided if microgreens are produced in a controlled environment with little microbial contamination. Microgreens may be cultivated indoors, so the propagation materials may be properly decontaminated (Kou et al. 2015).

Chandra et al. (2012) reported the effects of different sanitizers such as chlorine, citric acid, ascorbic acid, and ethanol spray on the quality and microbial population of *Brassica campestris var. farinose* microgreens. The study found that a spray of citric acid and ethanol might successfully substitute the chlorine normally used to wash microgreens. Simply washing the microgreens with chlorinated water (without affecting taste and flavor) can prevent microbial growth in the postharvest stage (Mir et al. 2017). Kou et al. (2014) investigated the positive role of preharvest calcium application on the quality of broccoli microgreens. Studies on the effects of various pre/postharvest cleaning may include calcium treatments on the quality and shelf life of broccoli microgreens. It was noticed that $CaCl_2$ without postharvest wash was the most efficient treatment as compared with Ca lactate and Calcium amino acid chelate. Since broccoli microgreens are so fragile in nature, dipping/washing and drying them reduces their quality drastically. The postharvest quality and shelf life could be extended to 21 days. The addition of 10 mM calcium chloride to the microgreens not only tripled the calcium concentration but also, there was an increase in biomass synthesis, superoxide dismutase activity, and peroxidase activity in microgreens as well as a substantial reduction in microbial growth during storage.

Key areas which required to be addressed are (Bandyopadhyay et al. 2002) testing and validation of microgreens' health-promoting effects in both animal models and human studies; (Berba and Uchanski 2012) determining the bioavailability of bioactive components from microgreens; (Bhatt and Sharma 2018) identifying the mechanism of action of microgreen components on cellular pathways in inflammatory processes to also include the microbiome; and (Bulgari et al. 2021) determining the optimum growing conditions and postharvest processing and the effects of these factors on the nutrient content of microgreens. Therefore, further studies are necessary to fully realize the value of microgreens in human health (Choe et al. 2018).

Shelf life extension of microgreens can be achieved using the relatively modern approach of microencapsulation. The vitamin-rich *Vigna radiata* microgreens could be locked within microspheres made from inert materials using microencapsulation technologies (Fig. 5.2) such as ionotropic gelation and lyophilization (Nair and Lekshmi 2020).

Fig. 5.2 Vitamin-rich microcapsules developed from various microgreens via microencapsulation

Future research aimed at improving the quality and shelf life of microgreens, on the other hand, should be encouraged in order for the microgreen sector to thrive.

5.8 Microgreen Market Challenges

Microgreens are gaining popularity across the world since they are 40 times more nutritious than mature veggies. Microgreen cultivation has both environmental and economic benefits. Consumption patterns and income levels influence the progression of the microgreens market to its true development potential. Climate and societal emergencies, like the COVID-19 epidemic, compel us to reconsider how we create food fortified with bioactive components that enhance health and maintain the immune system. Under such circumstances, microgreen culture should be considered and implemented as a remedy (Paraschivu et al. 2021).

According to recently available data and market research, the microgreens industry is on the rise throughout the world, particularly in cities owing to the rapid use of indoor and vertical farming systems; however, lack of knowledge about shelf life, food safety, and packaging of microgreens act as a primary challenge in many developing and underdeveloped areas. In such a setting, the promotion of microgreens to the general population must take precedence. The popularity and sales of microgreens will rise as more people become aware of the market. Furthermore, shelf life, food safety, and packaging of microgreens should be addressed, in addition to marketing or farmers who cultivate microgreens at home or on the farm. Customers must, thus, have a thorough understanding of microgreens before the industry can be established in a particular location (Van Rooyen et al. 2021).

5.9 Microgreens: The Future Food

NASA scientists are investigating the difficulties and advantages of cultivating microgreens in space. Microgreens are suited for space travel because they can be grown on a static shallow substrate with little to no nutrients, alleviating poor crop performance in microgravity hydroponics due to low oxygen and nutrient solubility. Hence it is an exciting, novel area of research (Dey and Chakraborty 2021). Plants are prized in space for their ability to renew oxygen, fix nitrogen, offer essential nutrients and fresh ingredients, and boost astronaut morale over long periods away from Earth (Kyriacou et al. 2017).

Microgreens are perfect for salads due to their small size, minimal nutrition, growth medium requirements, and short growing period. Seed germination, watering plants, anchoring plant roots, and restricted resources are just a few of the obstacles that come with growing food in space. Padgett and Smith (2018) outlines how films are made and tested to keep seeds in place during growing. Microgravity, according to Vandenbrink and Kiss (2016), may impact epigenetic processes and, as a result, gene expression in plants.

Furthermore, food safety problems are crucial for astronauts, who have limited access to medical treatment and are confined together in a tiny area during space travel. To guarantee that seeds do not retain human infections, they must be cleaned (Padgett and Smith 2018).

Novel applications, such as meals or ingredients made from discarded microgreens or microgreens nearing the end of their shelf life, are the last topic of study that has yet to be fully explored. Despite the importance of extending the shelf life of microgreens, which has been described in this study to decrease waste, innovative processing, and reformulation of discarded microgreens into new products is an area of future research.

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