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Review

A Review of The Effects Of Light-Emitting Diodes (LEDs) on The Growth of Sunflower Microgreens and Their Nutritional Potential

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ABSTRACT

Sunflower (*Helianthus annuus*) microgreens have become known as a potent source of essential nutrients and bioactive compounds with numerous health benefits. The microgreens industry has traditionally favored popular microgreens from the *Brassicaceae* family such as kale, rocket, and broccoli. Sunflower microgreens are characterized by their richness in vitamins, minerals, antioxidants, and phytochemicals that contribute significantly to a nutritious diet. However, their nutrient content can be influenced by various factors, including growing conditions and lighting. Light-emitting diodes (LEDs) offer precise control of light spectrum, light intensity, and lighting duration, enabling customized lighting systems optimized for growing sunflower microgreens. Pre-treatment and optimal harvest timing affect the quality and yield of microgreens, and sunflower microgreens are no exception. Accordingly, sunflower microgreens are typically harvested within 7 days of cultivation, making them ideal for mass production. The use of LED technology in the cultivation of microgreens offers the opportunity to further enhance their nutritional value and therapeutic potential. This review provides an overview of the benefits of sunflowers, sunflower microgreens, pre-treatments, and the ideal harvest period. The potential improvements from LED lighting are discussed and its impact on human health is explained.

Key words: Sunflower, microgreen, light-emitting diodes (LEDs), human health

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INTRODUCTION

One of the most feasible, sustainable, and cost-effective strategies advocated by the Food and Agriculture Organization (FAO) to improve the nutritional value or quality of diets is addressed through a food-based approach to agriculture (Thompson & Amoroso, 2014). Recently, the importance of vegetables as an important and affordable source of micronutrients, especially dietary fiber, has greatly increased. A decade ago, the young form of leafy green vegetables known as microgreens gained a reputation as an innovative culinary ingredient which are consumed in an immature state (Treadwell *et al.*, 2020).

Essentially, microgreens are eaten raw to retain maximum nutrition while preserving the original flavor associated with the selected flora to provide the ultimate satisfaction to 'raw foodists', keeping all chemical substances unchanged and providing the consumer with the peak of nutrition and health benefits (Sharma *et al.*, 2022). Microgreens are tender edible seedlings grown from the seeds of various vegetables, aromatic herbs, herbaceous plants, and edible wild plants (Ghoora *et al.*, 2020a). The harvesting period varies depending on the desired species used, which usually takes about 1 to 3 weeks after germination when the cotyledons have fully developed and the first true leaves appear (Renna *et al.*, 2017).

Owing to their health-enhancing and disease-preventing qualities, microgreens are defined as 'functional foods'. The popularly marketed families of microgreens are mainly from the *Brassicaceae* family and the list continues with *Asteraceae*, *Chenopodiaceae*, *Lamiaceae*, *Amaryllidaceae*, *Apiaceae*, *Amaranthceae*, and *Leguminaceae* with plants such as cabbage, broccoli, kale, rocket, sunflower, and parsley (Sharma *et al*., 2022). To impress customers in the presentation of food, catering establishments combine and integrate various micrograsses as decorative elements that improve the appearance and health value of the food offered. Restaurants in Belgrade used 28% of microgreens from sunflowers, among other microgreens, to garnish prepared meals (Božić & Milošević, 2020). Sunflower microgreens are rich in proteins, ascorbic acid (vitamin C), total phenols, flavonoids, fiber, and high antioxidant activity (Pająk *et al*., 2014).

Microgreens, like most plants, require various factors for optimal development and the light source is one of them. The quality and quantity of light directly influence the growth of plants and their chemical composition. Accordingly, light can be used as a customizable factor for the extraction of plant-based materials or metabolites (Lobiuc *et al*., 2017).

The use of LED-based devices offers the possibility of modifying the intensity and composition of the light spectrum (Bian *et al*., 2018) so that the optimal lighting conditions for a particular plant at its preferred stage of development can be used to reduce energy losses and optimize plant development (Han *et al*., 2017). Modern informatics devices enable the design and modification of complex lighting recipes by accurately selecting the most efficient spectral composition. By using light-emitting diodes (LEDs), separate regulation of each wavelength is possible within a fairly narrow range (about 40 nm accuracy per bandwidth) compared to the old-fashioned incandescent bulb lamps (Loconsole *et al*., 2019). In addition, LEDs enable energy savings of up to 70% compared to conventional light sources (Singh *et al*., 2015), as LEDs operate at significantly lower temperatures, have less impact on the growing environment, and generally have a longer usage period.

Certain light spectra are said to stimulate the growth and development of plants and influence general plant morphology. The red and blue spectra are generally considered to be the most important light regions that are crucial for plant growth and developmental stages (Chen *et al*., 2017). Nevertheless, theoretically unprofitable spectral regions such as the wavelengths close to yellow or green also play a role in influencing crop quality (Olle & Viršile, 2013). Red light promotes biomass accumulation, growth, and photosynthesis in lettuce (Loconsole *et al*., 2019). Researchers Lee *et al*., (2016) found that a low ratio of red to far-red (R:FR) has a significant effect on plant growth, structure, and production of root metabolites. Far-red light in combination with red LED light or with cool white fluorescent light was reported to be effective in promoting biomass accumulation and leaf length (Li & Kubota, 2009). Blue LED lighting is efficient in stimulating photomorphogenesis and adaptive phenomena such as the regulation of stomata opening/closing as well as biomass accumulation, chlorophyll, and anthocyanin biosynthesis (Li & Kubota, 2009; Chen *et al*., 2017). Green light illumination helps regulate leaf expansion, stomatal conductance, and stem elongation of plants. In addition, green LED lighting has been shown to lead to increased dry matter accumulation and enhanced growth stimulation (Kim *et al*., 2005).

Using LED illumination of specific and defined wavelengths, favorable environments can be manipulated, resulting in several benefits, such as maximizing plant growth, optimizing flavor and pigmentation, morphology, and improving the accumulation of bioactive compounds (Lobiuc *et al*., 2017). The current review provides a comprehensive comparative overview of sunflower microgreens, the effects of LEDs on microgreens, efficient post-harvest and pre-harvest practices, and an overview of the nutritional importance of microgreens.

Sunflower

The sunflower is a short-lived, seasonal plant species belonging to the family Asteraceae and the genus Helianthus, of which over 70 species are known worldwide. The name “sunflower” is derived from its size and appearance, which resembles the sun. Another origin states that the name was chosen for its rotation around the sun (Adeleke & Babalola, 2020). The flower is characterized by a yellow inflorescence, a large circular flower head (bearing the achenes that develop into mature seeds) that faces directly towards the sun’s rays, as well as rough, broad, alternate but coarsely toothed leaves, a deep taproot and rough, hairy stems. The sunflower originally comes from the temperate regions of North America with temperatures between 20 and 25°C and was later brought to Europe by Spanish explorers in the 16th century. The flower parts of the sunflower have an ornamental and aesthetic value and are available in different colors and sizes, with the different cultivars recognizable by their colors ranging from cream to yellow (Vilvert *et al*., 2018).

Sunflower is the world’s fourth most important oilseed, known for its high profitability and economic value, lagging behind major oilseeds such as soy, rapeseed, and safflower. Nutrient deficiencies and unfavorable environmental conditions, including climatic, soil, and management factors, can lead to lower yields of sunflower seeds, oil, and other products. The use of organic and synthetic fertilizers can affect sunflower yield and quality (Adeleke & Babalola, 2020). It is mainly grown by plant scientists to breed varieties with high oil content under optimal conditions for maximum yield and productivity, which requires fertile soils, adequate rainfall, and favorable environmental conditions. An improved supply of vital micronutrients such as potassium increases plant productivity and increases the plant's resistance to drought and environmental stresses (Enebe & Babalola, 2018).

Sunflowers account for around 87% of vegetable oil production, making them the favored choice over other oilseed crops. They are an economically advantageous and promising agricultural commodity, that offers numerous benefits such as enhancing valuable market products, income generation, and poverty alleviation. Nevertheless, the scarcity of viable seeds for farmers and unfavorable weather conditions have meant that its potential cannot be fully exploited throughout the food supply chain. By utilizing its yield effectively, sunflower could serve as an alternative to existing major oil crops such as palm oil, palm kernel oil, soybean, rapeseed, and peanut (Bassegio *et al*., 2016). Sunflowers have proven to be an economical oil crop that can be integrated into local farming systems and promote soil health and biodiversity in crop rotations. With their robust, adaptable characteristics, they thrive in diverse environments that do not rely on high fertility levels like maize, wheat, and other crops. In addition to oil production, sunflowers are a versatile food source that can be consumed in a variety of ways (raw, roasted, cooked, dried, or ground).

To meet the ever-growing demand of the food industry around the globe, large quantities and different types of sunflowers are cultivated worldwide. In general, two types of sunflowers are cultivated, namely the oilseeds for the production of sunflower oil and the confectionery for consumption. The ornamental sunflower seeds are mainly used for home consumption and not production due to their smaller seed size, i.e. they are mainly used for aesthetic purposes. Researchers found that the seed size of sunflower seeds significantly affects seed germination (Krstić *et al*., 2022). In appearance, the oily sunflower seeds are black and have a thin shell attached to the kernel. These oilseeds have a significantly higher oil content than the non-oily varieties, which are larger and are mainly used for consumption. The confectionery or non-oilseed variety is visually larger than the oilseeds. The color of the seeds ranges from black and white to black with white stripes. The sunflower oil extracted from the oilseeds is considered safe and suitable for human consumption and has a low cholesterol level. The edible oilseeds that are important for human consumption include sunflower oil, rapeseed oil, soya bean oil, etc. These oils from the respective oilseeds can be used as compound ingredients in food preparation. On the other hand, other varieties are also significant as oilseeds, though they are typically used in smaller amounts (Eryilmaz & Yesilyurt, 2016).

Sunflower microgreens

Previous research on microgreens has mainly focused on vegetable plants or those from the Brassicaceae family. As one of the viable and nutrient-rich foods, sunflower microgreens have the potential to compete with plants from the Asteraceae family. The concept of microgreens has recently attracted much attention, defining a new category of vegetables that can be categorized between "sprouts" and "baby lettuces." They have unique characteristics that differ from sprouts, baby lettuces, and fully mature vegetables (Murphy *et al*., 2010; Renna *et al*., 2017).

Microgreens have a more robust flavor profile than sprouts and are widely recognized worldwide. They exhibit a wide variety of leaf and cotyledon colors, shapes, and varieties, resulting in a visually stunning combination of taste, color, and texture. Microgreens can compensate for nutrient deficiencies and acclimatize consumers to their sensory properties, positioning them as the potential next generation of "superfoods" (Pinto *et al*., 2015; Kamal *et al*., 2020; Paradiso *et al*., 2020).

Although microgreens can be grown on a large scale in outdoor fields, they are mainly cultivated in greenhouses, in controlled environments, or in soilless systems such as hydroponics under artificial lighting (LED). This method improves plant growth, yield, quality, and accumulation of bioactive compounds without being limited by light conditions (Di Gioia *et al*., 2017; Ying *et al*., 2020). Among the most critical factors affecting the production, shelf life, composition and overall economic viability of crops are light, temperature, water, and nutrient supply (Harakotr, 2019).

The advantages of microgreens over conventionally grown greens are that they have a short growth cycle and are rarely attacked by pests. This enables the production of fresh organic harvests without the use of pesticides or fertilizers in a limited space. Sheltered and indoor cultivation is also less susceptible to extreme weather and environmental conditions, and soilless growing conditions are less prone to infestation by pests and soil-borne bacteria. In addition, their energy requirements are lower compared to sprouts and mature vegetables, making them more environmentally friendly than conventionally grown vegetables (Sharma *et al*., 2022). Research comparisons have shown that growing microgreens is a more sustainable and cost-effective option than growing fully mature vegetables. Research suggests that fully mature broccoli uses approximately 158–236 times more water and requires more time to produce similar amounts of nutrients compared to broccoli microgreens grown in California's Central Valley. Broccoli microgreens also grow significantly faster, requiring only 5-7% of the time it takes to mature, and they require no fertilizer. Microgreens also produce less waste as they do not contain stems and leaves when preparing meals (Weber, 2017). At both micro and macro scales, growing microgreens in containers allows for the commercialization of microgreens that are harvested fresh for consumption, bypassing many of the harvest and post-harvest handling issues associated with mature vegetables (Kyriacou *et al*., 2016; Di Gioia *et al*., 2017).

Sunflower microgreens (Figure 1) belong to sprouting plants, which include pulses, oilseeds, cereals, and vegetables such as kale, rocket, etc. (Ebert, 2012). Sunflower microgreens have a refreshing texture and nutty flavor, similar to another sprouting plant, the soybean which has an appealing nutty flavor and unique texture (Di Gioia *et al*., 2017). In addition to the unique flavor, sunflower microgreens can be cultivated from seed to sprouts within 7 days, which is consistent with the duration of sunflower microgreen growth in Dalal *et al*. (2020), where they investigated the postharvest quality of microgreens under the influence of organic acids and ethanol treatments. Most sunflower microgreens were grown on solid medium, e.g. in combinations of vermiculite, perlite, coco peat, soil mix, etc. Ciuta *et al*. (2020) compared two cultivation systems (cultivation banks with a mixture of peat and perlite and vertical hydroponic systems) with sunflower and different microgreens and concluded that the vertical hydroponic system generally gave better results compared to the cultivation banks for most of the microgreens studied. In addition, the vertical hydroponic system leads to a slightly higher production per cultivated unit area, compared to the flow bench system.

Fig. 1. Sunflower microgreens (5 days of growth)

LIGHT EMITTING DIODES: A PROMISING LIGHT SOURCE

Research into the benefits of light-emitting diode lighting for plant growth and development has increased significantly in recent years due to the numerous advantages that light-emitting diodes (LEDs) offer compared to conventional artificial light sources. These advantages include compact size, cost-effectiveness, longer lifetime, and durability (Massa *et al*., 2008; Zhang *et al*., 2020) which are far superior to their predecessors (high-pressure sodium vapor lamps and fluorescent lamps).

High-pressure sodium vapor lamps require a high voltage and emit a lot of heat. They also contain only about 5% blue light, which is significantly less than the 18% found in natural sunlight (Islam *et al*., 2012). Fluorescent lamps, on the other hand, offer limited photon output, less efficient energy conversion into light, and a relatively short effective lifetime (Rehman *et al*., 2017). Plants are not able to absorb all light equally, as different wavelengths have different effects on plant growth and photosynthesis. The most favorable spectrum for photosynthesis is in the 400 to 700 nm range, known as photosynthetically active radiation (Rehman *et al*., 2017), and this is where the role of LEDs comes into play. LEDs can be manipulated to emit precise wavelengths and specific bandwidths, allowing wavelength matching to the photoreceptors of plants. Light quality, i.e. the spectral distribution, wavelength, or color of light, has a significant impact on plant development, metabolism, and physiology (Johkan *et al*., 2010). The ability to regulate light quality, including intensity, enables improvement in plant growth, development, and nutritional content. This ability is beneficial in the development of plant lighting systems.

Light spectra with specific wavelengths have proven to be beneficial in stimulating plant growth or influencing plant morphology. While red and blue light regions are generally recognized as crucial for plant growth and development (Chen *et al*., 2017), other wavelengths, such as those in the yellow or green spectrum, play a role in influencing crop quality (Olle & Viršile, 2013).

Red light wavelengths promote flowering, stem growth, and fruit formation. Yanagi *et al*. (1996) conducted a study in which they compared the effects of red (660 nm) and blue (450 nm) LEDs on the photosynthetic rate of strawberry leaves and found higher quantum efficiencies with the red LEDs. Another study investigated the combined effect of ethylene and red illumination wavelength (660 nm) on carotenoid accumulation and gene expression related to carotenoid biosynthesis in the flavedo of Satsuma mandarin. The study showed a significant increase in the content of β-cryptoxanthin and lutein as well as total carotenoid accumulation under red light irradiation (Ma *et al*., 2015). Red light increases the growth, biomass accumulation, and photosynthesis of lettuce (Loconsole *et al*., 2019). Lee *et al*. (2016) have shown that a low ratio of red to far-red (R:FR) significantly affects plant growth, structure, and production of root metabolites. Huan *et al*. (2012) investigated the effects of photoperiod under red LED on the growth and quality of sunflower microgreens. The results indicate that increasing the photoperiod from 0 to 12 hr per day significantly suppresses hypocotyl elongation and increases cotyledon area, while increasing the photoperiod from 0 to 16 hr per day significantly increases chlorophyll and carotenoid content. Theparod and Harnsoongnoen (2022) concluded that red LED lighting is the most effective for sunflower seed germination.

The wavelengths of blue light stimulate plant development by promoting vigorous root growth and increased photosynthetic activity. It is generally used independently to promote the growth of seedlings when flowering is undesirable. Blue LED lighting effectively stimulates photomorphogenesis and adaptive responses, including the regulation of stomatal opening and closing mechanisms (Li & Kubota, 2009; Chen *et al*., 2017). Blue LED lighting is effective in increasing fruit quality, yield quantity, and disease resistance in tomatoes (Xu *et al*., 2012). In addition, Terfa *et al*. (2013) observed an increase in leaf thickness and photosynthetic capacity of hybrid tea roses when blue light was increased from 5 to 20%. A study on cucumber by Hogewoning *et al*. (2010) emphasized the potential benefits of blue light in regulating photosynthetic functions. Another study on cucumbers (*Cucumis sativus*) under blue and red lighting showed that blue lighting suppressed stem elongation but promoted elongation growth, although this effect varied depending on the species (Hernández & Kubota, 2016). Theparod and Harnsoongnoen (2022) found that the percentage of germination of sunflower microgreens under blue lighting was the lowest among all LEDs studied.

Recent studies have shown that plants absorb part of the green light to utilize it for their photosynthetic processes. The green spectrum plays a role in the regulation of leaf expansion, stomatal conductance, and elongation of plant stems. In addition, studies indicate that green LED lighting promotes dry matter accumulation and stimulates growth (Kim *et al*., 2005). Johkan *et al*. (2012) reported that higher intensities of green LED light promote plant growth and short wavelengths are available for active plant growth. Kasajima *et al*. (2007) found that green-yellow light at 540 nm increased leaf emergence in certain plants by up to 50%. Thale cress (*Arabidopsis thaliana*) showed shading symptoms under green light, with cryptochrome receptors and an unidentified light sensor playing a role in the plant's adaptation to a green environment (Zhang *et al*., 2011). Hernández and Kubota, (2016) studied the growth and development of cucumber under a combination of 28% green light with red and blue light sources and concluded that the 28% green spectrum had no response on the plant. X. Ma *et al*. (2015) showed that the inclusion of green lighting in the combined spectrum of red and blue LED lighting resulted in stronger growth and better development of potato plantlets *in vitro* compared to combined treatments without green. No detailed study has yet been conducted on the effects of green lighting on sunflower microgreens.

Monochromatic red or blue LED, lighting or their combination can increase photosynthetic activity to support plant production and regulate morphogenesis. Li *et al*. (2010) demonstrated that a combination of blue and red LED (lighting in a 1:1) ratio is more effective in achieving higher fresh and dry weights in upland cotton. Similar results were observed with equal proportions of blue and red LEDs in vitro plant cultures of bananas (Nhut *et al*., 2001), strawberries (Nhut *et al*., 2003), and chrysanthemums (Kim *et al*., 2004). Lin *et al*. (2013) reported that mixed red, blue, and white LEDs with peak powers in the blue and red range, complemented by broad spectral energy of 500–600 nm, had various positive effects on the growth, appearance, nutrition, development and nutritional quality of lettuce plants. Samuolienė *et al*. (2010) suggested that a combination of red and blue spectral regions is essential for the growth of frigo strawberries. Similarly, Hung *et al*. (2015) found that mixed red and blue LEDs are highly effective light sources for strawberry culture systems utilizing encapsulation technology. They observed vigorous growth of shoots and plantlets when using a mixed spectrum of 70% red and 30% blue LEDs.

PRE-TREATMENTS AND OPTIMAL HARVESTING PERIOD

Various pre- and post-harvest treatments such as changing growing conditions, pre-harvest treatments, proper harvesting, changing the storage atmosphere and transport conditions, and adding value into more stable, acceptable, and nutritious products are important considerations for better utilization of microgreens (Xiao *et al*., 2014; Paradiso *et al*., 2018). Seed is the basic and essential component for ensuring quality production of any crop, especially microgreens.

Various seed treatments can improve seed quality. For example, seeds of large-grain crops such as peas, beet, and sunflowers are commonly soaked in water before sowing to accelerate germination (Sharma *et al*., 2022). Halo priming with potassium nitrate (KNO_3) at concentrations of 50 mM and 150 mM or the application of growth regulators such as gibberellic acid (GA_3) at concentrations of 25 μM and 250 μM was found to improve germination rates and shorten the average germination time of chicory and endive seeds (Tzortzakis, 2009). These results indicate the potential effectiveness of KNO_3 and GA_3 treatments to ensure rapid and consistent seedling emergence, which is efficient for the production of microgreens. Halo priming treatment with 1% $CaCl_2$ for 12 hr showed the highest germination rate (86.66%), germination index (35.69), and seedling vigor index (1833.80) among the different treatments, proving to be an effective method for yard-long bean germination (Karim *et al*., 2020). In addition, biofortification can be a useful approach to improve productivity and production quality. Biofortification of buckwheat seeds with selenium (0.147 μg) and iodine (14.7 μg) resulted in a 50–70% increase in yield (600–800 g/m^2) compared to individual application of selenium and iodine in microgreens (Germ *et al*., 2019).

Microgreens are usually harvested when the first set of true leaves (fully grown cotyledons) appears and has reached the desired height. This process usually takes 7-21 days from sowing to harvest, although the timing can vary depending on the plant type and growing conditions (Mir *et al*., 2017). It is usually recommended to harvest in the morning, as the plant seedlings undergo respiration slowly and have a higher moisture content at this time (Saini *et al*., 2017). Visual quality is also a crucial parameter that influences consumer acceptance. The optimal aesthetic quality of radish microgreens was observed after the first week of growth, which corresponds to a low respiration rate (Berba & Uchanski, 2012). In addition, each microgreen can be targeted for specific bioactive compounds and harvesting stages can be standardized accordingly. Sunflower microgreens are typically harvested 7 days after cultivation, when the cotyledons are fully mature (Figure 2). With evolving market trends, it is becoming increasingly important for researchers to focus on cultivating chemical-free and, functionally enriched seedlings to meet consumer demand and satisfaction. This opens a wide field for researchers to explore potential techniques and methods to maximize the enrichment of various bioactive compounds and biomass in microgreens.

Fig. 2. Harvested sunflower microgreens after 1 week.

Functional importance and impact on human health

In recent times, more and more importance has been placed on personal health, driven by the increase in various health problems and the continued decline in overall well-being (Bhaswant *et al*., 2021). This change has prompted people to include leafy greens, fresh fruits, and vegetables in their daily diet to ensure optimal nutrition. As a result, there has been an increased interest in functional foods that provide abundant nutrients at an affordable cost and are minimally affected by modern agrochemicals.

Sprouts and microgreens have proven to be particularly beneficial options due to their shorter growing time and lower maintenance requirements compared to fully mature plants such as fruits and vegetables (Sharma *et al*., 2020). Microgreens, in particular, are incredibly easy to cultivate, requiring minimal resources and no complex growing systems such as soil or additional nutrients (Aloo *et al*., 2021). These young sprouts, including the radicle, are usually eaten raw and are rich in fiber and a variety of phytochemicals that contribute significantly to human health (Aloo *et al*., 2021).

Ascorbic acid, also known as vitamin C, plays an important role in bodily functions and is considered an essential bioactive compound with antioxidant properties. Di Bella *et al*. (2020) investigated the content of ascorbic acid in *Brassica oleracea* microgreens and observed fluctuations during the different phases of plant growth. Their results suggest that microgreens may have higher ascorbic acid contents compared to other stages such as sprouts, baby greens, and mature plants. The results are supported by Pająk *et al*. (2014) whereby sunflower sprouts (Harvested after 5 days) displayed two times higher antioxidant potential compared to seeds through the Ferric Reducing Antioxidant Power Assay (FRAP). In addition, Ghoora *et al*. (2020b) showed that sunflower microgreens (86.3 ± 3.0) are a notable source of ascorbic acid, although they might be surpassed by other microgreens such as roselle (123.2 ± 4.0) in terms of content.

β-Carotene, an organic compound with a red-orange color, serves as a precursor to vitamin A and is often found in red, orange, and yellow-colored plants. It plays a crucial role in triggering apoptosis in cancer cells, neutralizing free radicals, and boosting the production of natural killer cells, thereby strengthening the immune system (Miyazawa *et al*., 2019; Maurya *et al*., 2021). Microgreens are rich sources of β-carotene and provide consumers with significant levels of pro-vitamin A. Ghoora *et al*. (2020b) analyzed the phytochemical composition of ten culinary microgreens using High-performance liquid chromatography and photodiode array detector (HPLC-DAD) and revealed their different levels of β-carotene and other beneficial compounds such as vitamin E and ascorbic acid. The study showed that the concentration of β-carotene ranged from 3.1 to 9.1 mg per 100 mg of microgreens, with fennel, radish, and mustard having the highest levels, while sunflower microgreens contained 4.5 ± 0.2 mg.

In addition, α-tocopherol, a vital phytochemical found in microgreens, plays a crucial role in numerous bodily functions, including nerve impulses, muscle movement, strengthening the immune system, and regulating the formation of free radicals (Miyazawa *et al*., 2019; Szewczyk *et al*., 2021). Studies have shown that microgreens are rich sources of vitamin E that help consumers optimize bodily functions (Ghoora *et al*., 2020a). Radish microgreens had the highest α-tocopherol content at 58.6 mg per 100 g. Sunflower microgreens contained 48.7 mg per 100 g, while mustard and fennel microgreens also had significant amounts of α-tocopherol (Ghoora *et al*., 2020a).

Phylloquinone, a form of vitamin K found in various vegetables and green leafy plants, was analyzed in six microgreen species by Xiao *et al*. (2015). These included red amaranth, Dijon mustard, pepper cress, bull's blood beet, opal basil, and Chinese radish. Their study found consistent phylloquinone levels between 2.1 and 4 g/kg in all species, regardless of plant type. Table 1 depicts some of the important compounds and health benefits obtainable from microgreen consumption.

Essential minerals are vital nutrients that are essential for human health and are mainly consumed through food (Martínez-Ballesta *et al*., 2010). These minerals can be divided into two categories: Macroelements (e.g. Ca, Mg, P, K, Na) and Microelements (or trace elements such as Fe, Zn, Cu, Mn), each of which plays a central role in various biological processes in both plants (Maathuis, 2009) and humans (Scherz & Kirchhoff, 2006). A deficiency of these elements can lead to metabolic disorders, severe organ damage, and serious diseases in humans (Dos Santos *et al*., 2013). Renna and Paradiso (2020) investigated the nutrient composition of three microgreen varieties from the *Brassica* family (cauliflower, broccoli, and broccoli rabe) grown with different NH_4:NO_3 nutrient solutions. Their results showed that these microgreens are rich in minerals such as Na, Cu, Mn, Ca, Mg, K, Zn, and Fe, as well as macroelements, proteins, fiber, α-tocopherol, β-carotene, and others.

In a separate study by Ghoora *et al*. (2020a), sunflower microgreens had one of the highest total protein contents (3.9 g/100 g), closely followed by fennel (4.4 g/100 g). Sunflower microgreens were also rich in total, soluble, and insoluble dietary fiber. While the zinc content in sunflower microgreens was comparatively low, they were rich in other important minerals such as calcium, magnesium, potassium, phosphorus, sodium, and iron.

Phenolic antioxidants are plant compounds or metabolites found in microgreens that help promote metabolic activity, reduce inflammation, and prevent oxidation by free radicals prevention (Kumar & Goel, 2019). Research by Tan *et al*. (2020) investigated the phenolic antioxidants, including tannins, phenolic acids, and anthocyanins, in various microgreens sourced from local and commercial farms to evaluate their antioxidant and organoleptic properties, such as flavor, aroma, and color (Tan *et al*., 2020). Microgreens have a total phenolic content of 10.71 to 11.88 mg/g, which is significantly higher than that of their mature counterparts and sprouts, with broccoli showing a tenfold increase. These phenolic compounds play a role in improving glucose homeostasis and other metabolic processes in the human body (Tan *et al*., 2020).

Table 1. Health benefits of different components present in popular microgreens

Compound	Microgreen/ Crop	Nutritional benefits	Reference(s)
Ascorbic acid (Vitamin C)	Radish, Roselle, Sunflower, etc.	I. Assist and support the immune system and function II. Improves night vision III. Overall eye health protection	Ghoora *et al*., 2020a; Ghoora *et al*., 2020b; Sharma *et al*., 2022
β-Carotene	Fennel, Radish, Sunflower, etc.	I. A crucial role in the apoptosis of cancer cells II. Neutralize free radicals III. Strengthen the immune system	Maurya *et al*., 2021; Miyazawa *et al*., 2019
α-tocopherol (Vitamin E)	Fennel, Mustard, Sunflower, etc.	I. Regulating nerve impulses II. Regulate muscle movement III. Strengthen immune system IV. Anti-oxidant activity	Miyazawa *et al*., 2019; Szewczyk *et al*., 2021; Ghoora *et al*., 2020a
Phylloquinone (Vitamin K1)	Red amaranth, Dijon mustard, peppercress etc.	I. Bone health II. Tooth health III. Muscle function	Sharma *et al*., 2022; Xiao *et al*., 2015

CONCLUSION

Sunflower microgreens have immense potential as a nutrient-rich superfood with numerous health benefits. These tiny greens offer a convenient and delicious way to promote human health and overall wellness. With their exceptional nutrient density and versatility in culinary applications, sunflower microgreens have proven to be a valuable addition to a balanced diet. Further investigation and research into the use of different LED lighting and its effects on sunflower microgreens are required to maximize the potential properties of sunflower microgreens. As technology advances, it is only a matter of time before more data is available on the overall benefits of sunflower microgreens and improvements can be made. Without neglecting the health-promoting properties of sunflower microgreens, further research would uncover additional benefits and applications that make them an increasingly popular choice for health-conscious consumers.

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ETHICAL STATEMENT

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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