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# A Review of Microgreens in Southeast Asia: Sustainable Agriculture, Phytochemicals, and Biological Activities

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## ABSTRACT

Microgreens are edible vegetable and herb seedlings with only 1–3 inches. Aside from their remarkable nutritional content, they can be grown easily in the city, and hence, they are acclaimed as emerging functional food. This review aimed to provide a systemic insight into the sustainable agriculture, phytochemicals, and biological activities of microgreens in Southeast Asia. The study was conducted by collecting the experimental findings from scientific articles published in reputable journals from 2000 to 2021 using electronic databases. The comparative analyses were conducted appropriately. Several species of microgreens from the Brassicaceae, Asteraceae, Lamiaceae, Apiaceae, and Amaranthaceae families were considered. Various methods for cultivating microgreens were discussed and the phytochemicals available in the microgreens were summarised. A comparison of phytochemical composition between the microgreens and macrogreens was conducted. Moreover, two well-known biological activities of microgreens, which are antioxidant and antimicrobial activities, were considered along with their experimental data. Finally. The impacts of microgreens consumption on human health were emphasized.

**Keywords:** biological activities, macronutrients, microgreens, micronutrients, phytochemicals, sustainable farming practices, urban agriculture

## 1.0 Introduction

Microgreens are tender vegetables and herb seedlings harvested after the development of the true leaf cotyledons. Microgreens give rise to unique features such as flavors, colors, and textures (Delian *et al.*, 2015; Weber, 2017). It was also described as "vegetable confetti" since it accented the dishes (Treadwell *et al.*, 2010; Kyriacou *et al.*, 2016; Charlesbois, 2018).

Recently, microgreens have emerged as one of the functional foods included as a culinary ingredient in salads and sandwiches due to their fascinating nutritional values and various sensorial features that support health and longevity (Chen *et al.*, 2020; Turner *et al.*, 2020). According to Xiao *et al.* (2015), the selected microgreens derived from mustard, basil, beet, radish, and amaranth species have achieved excellent acceptance scores from most consumers in the sensory evaluation, indicating that the microgreens industry has the potential to be marketed at a larger scale due to this early prediction of consumer acceptance.

Microgreens are particularly well-suited to be grown and distributed within metropolitan areas (Halloran & Magid, 2013). This is because microgreens are relatively easy to cultivate, grown indoors with limited resources, and have a short growth cycle. Microgreens have been part of the worldwide crusade for technology-based food production, as reported in the Controlled Environmental Agriculture (CEA) program (Benke & Tomkins, 2017). Furthermore, microgreens have been recognized by the Food and Agriculture Organization (FAO) of the United Nations as the future of smart food in the year 2018. It was also mentioned that microgreens are the hidden treasures of neglected and underutilized species, essential to successfully having zero-hunger communities worldwide (Li & Siddique, 2018).

Microgreens are known for their vast potential for reconstructing dietary patterns due to their splendid nutrient composition (Weber, 2017). It is usually rich in vitamins (Mir *et al.*, 2017), carotenoids (Xiao *et al.*, 2012), and micronutrients. In addition, different species of microgreens give rise to different classes of phytochemicals that have yet to be discovered. All these nutritional and phytochemicals contents in the microgreens can also be enriched through biofortification methods such as soil and foliar fertilization (de Valença *et al.*, 2017), light treatment (Sirtautas *et al.*, 2012), temperature effect (Xiao *et al.*, 2014), and preharvest spray (Kou *et al.*, 2015; Lu *et al.*, 2018) during the germination period. A growing body of evidence shows these edible microgreens have impressive biological activities i.e., anti-inflammatory, anti-obesity, cardioprotective, antidiabetic, and anticancer, that may contribute to the low risk of certain serious diseases (Choe *et al.*, 2018).

Therefore, the present study aims to provide a review of scientific literature addressing the potential of microgreens in urban agriculture within the context of nutritional and health aspects. This review focuses on the recent research and development of microgreen agriculture in Southeast Asia from 2000 to 2023. In the first instance, the review began by discussing the characteristics of microgreens as emerging urban agriculture that meets the criteria for sustainable agriculture. Subsequently, the nutritional and phytochemical compositions between microgreens and macrogreens were compared and discussed. Finally, the biological activities of microgreens and their effects on health were also reviewed.

## 2.0 Experimental

The literature was browsed for this review through PubMed, Google Scholar, Sci-Finder, Science Direct, Scopus, Universiti Malaya Library, ACS Publications, Springer, and Google search databases. The keywords “microgreen”, “micronutrients”, “sustainable agriculture”, “sprouts”, and “baby greens” were searched, and only relevant literature records in the English language between the years 2000 and 2023 in Southeast Asia were retrieved. There were three conceptual frameworks of text analysis mentioned in the study conducted by Lacity and Janson (1994), which were positivist, linguistic, and interpretive. These approaches were utilized mainly to differentiate the available academic research papers' quantitative, primarily qualitative, and qualitative contents.

## 3. Results and Discussion

### 3.1. Overview of Sustainable Agriculture

Sustainable agriculture is frequently linked to organic, regenerative, alternative, and ecological input farming (Reganold *et al.*, 1990). It meets the global population's needs without threatening the resources available for future generations (Farooq *et al.*, 2019), whereby the harvest must be yielded in a sufficient quantity of high-quality food while the resources are being preserved and should be harmless and environmentally profitable to support sustainable development (Prasad *et al.*, 2017). Several significant phenomena tormenting global food production are being pitched into thoroughly sustainable agriculture, e.g., groundwater pollution (Nakhli *et al.*, 2017), soil deterioration (Aliyas *et al.*, 2018), declining agricultural revenue (Dozier *et al.*, 2017), and threats to human health as well as flora and fauna habitats.

Ultimately, sustainable agriculture is not a return to the practices of the pre-industrial revolution; preferably, it incorporates conventional agricultural conservation techniques with modern technology. Modern machinery and certified crop, soil, and water management practices are used to create sustainable systems. Focus is imposed on rotating crops, soil building, and naturally managing pests.

#### 3.1.1. Importance of sustainable agriculture

Sustainable agriculture is indeed proposed from the environmental perspective about how natural resilience operates and applies to establishing food systems that are instinctively efficient and effective (Smith *et al.*, 2017). A sustainable agricultural approach contributes to the guarantee towards the forthcoming generations due to its regenerative ability.

Sustainable agriculture permits the use and recycling of water resources (Sikka *et al.*, 2018), which is essential to prevent the water bodies from being polluted. Water is an essential component of agriculture and is crucial to food security. Agricultural water management has now been repositioned to provide innovative and sustainable equipment. A technique that can sustain water resources is to have powerful irrigation techniques such as unique pop-up sprinklers (Dhakal *et al.*, 2015). In current conventional agriculture, irrigation still accounts for 70% of water losses in the agricultural process (Chartzoulakis & Bertaki, 2015). Nevertheless, urban agriculture usually applies night-time irrigation due to the efforts to reduce evaporative losses of water.

In addition, sustainable agriculture contributes to efficient energy consumption and production (Aschilean *et al.*, 2018) to lessen energy use at all levels. By implementing energy-efficient forms of agriculture, greenhouse gas emissions can be reduced by lessening fossil fuels in agricultural production and transportation. In contrast, unsustainable farming techniques are energy-intensive forms of agriculture and contribute significantly to greenhouse gas emissions since they rely profoundly on fossil fuels for production and transportation thousands of miles from the farming site to consumers.

Finally, the restoration and nourishment of the soil can be done via sustainable agriculture (Singh, 2021). Healthy soils are essential to retaining more moisture efficiently, hence, plants will be less vulnerable to disease outbreaks caused by pathogens or pests. In contrast, some conventional agriculture uses toxic chemicals as inputs and has substantial tillage, which is disparaging soil ecology (Tsion & Steven, 2019), and causing soil erosion. Consequently, the crops could be prone to infection, which will lead to water pollution, and the areas are predisposed to drought.

### 3.2. Urban Agriculture

Rapid urbanization is a significant cause of the changes in global land cover. According to the report given by the United Nations (2018), more than 68% of the worldwide population will live in cities by 2050. Urbanization is expected to result in the loss of prime agricultural areas between 1.6–3.3 million hectares by 2030 due to the construction of buildings (Kapil, 2019). The reduction of these areas demonstrated that urban green areas within the city are increasingly becoming significant for the urban ecosystem (Vargas-Hernández *et al.*, 2017).

Urban agriculture (also known as urban farming or urban gardening) is an agricultural practice that comprises the cultivation, dispensation, and allocation of predominantly horticultural products within a populated area (Saha & Eckelman, 2017). Through the efforts of many parties, e.g., scholars and environmentalists, high environmental awareness has caused city-dwellers to have a passion for agricultural development in the urban area. Therefore, the features of urban, which allow the production of several types of crops that render an economical utilization of financing, technology, and facilities as opposed to other horticultural modes, are worth noticing.

#### 3.2.1. Benefits of Urban Agriculture

In urban areas, the food system is intricately related to the global provision of food. The globalized food system has brought many benefits to urban areas, such as consistently delivering food at lower prices throughout the year (Mohan *et al.*, 2020). However, considering the scarcity and lack of natural resources and long-term climatic changes on the Earth, urban agriculture is needed. Urban agriculture can enable urbanites to become partly self-sustaining and diversify their food choice (Granzow & Jones, 2020). Further advantages can be achieved through these practices, such as higher food and nutrition security, local economic development, and environmental quality (Hodgson *et al.*, 2011).

##### 3.2.1.1. Food and Nutrition Security Enhancement

Urban agriculture is a global solution to support food and nutrition security, particularly in developing cities such as Manila, Lahore, and Hanoi. As evidenced by studies conducted by De Guzman (2017), Waseem *et al.* (2019), and Nguyen *et al.* (2020), the introduction of urban agriculture plays an essential role in stabilizing household food security and mitigating the risk of malnutrition, as portrayed by Islam and Siwar (2012). This strategic approach becomes even more significant in urban food system disruptions, such as those caused by natural disasters like earthquakes, floods, and pandemics. Notably, research by Guzman *et al.* (2015) on the island of Negros, Philippines, reveals a tangible reduction in malnutrition cases among urban and peri-urban children—from 40% to 25%—within a mere two years of implementing urban agriculture practices. Through these findings, it becomes evident that urban agriculture is a robust mechanism to enhance food and nutrition security, offering a tangible and swift response to immediate challenges faced by urban communities.

The transformative impact of urban agriculture on community food and nutrition security lies in its ability to elevate the variety, quantity, and quality of perishable foods within urban areas (Steenkamp *et al.*, 2021). By fostering local cultivation, urban agriculture provides a resilient source of nutrition, offering a buffer against the uncertainties of external supply chains (Yuan *et al.*, 2022). This localized approach not only ensures a more consistent and accessible food supply but also empowers urban communities to actively participate in securing their nutritional needs. Essentially, urban agriculture emerges as a dynamic force, not only mitigating the risks associated with malnutrition but fundamentally improving the overall quality of the urban food environment (Opitz *et al.*, 2016). Through its multifaceted contributions, urban agriculture emerges as an essential strategy for fortifying urban resilience against the challenges posed by food insecurity and nutritional deficiencies.

#### 3.2.1.2. Diversification of Diets

Diversification of diets emerges as a significant benefit of urban agriculture, addressing a transition from the traditional reliance on a limitation of staple foods. In urban environments, where dietary habits may be constrained by the availability of convenient yet nutritionally limited options, cultivating a diverse range of fruits, vegetables, herbs, and microgreens becomes indispensable. Urban agriculture empowers communities to embrace a spectrum of nutrient-rich foods, ensuring a more balanced and comprehensive nutritional intake (Tasciotti & Wagner, 2015). The cultivation of diverse crops not only broadens the palette of available food options but addresses the nutritional deficiencies that may arise from overreliance on a few staple items. This diversification is advantageous in combating malnutrition and promoting overall health, fostering resilient and robust communities better equipped to meet their dietary needs (Gerster-Bentaya, 2013).

Reducing dependency on limited staple foods is a significant aspect of urban agriculture's impact on diet diversification (Oktafiani *et al.*, 2021). The practice encourages a shift towards embracing the richness of locally cultivated produce, enhancing a more sustainable and health-conscious approach to food consumption. By promoting a diverse range of crops within urban landscapes, communities enhance their nutritional resilience and contribute to the preservation of agricultural biodiversity (Langemeyer *et al.*, 2021). This diversification is a buffer against the potential risks of dependence on a few staple items, such as susceptibility to crop failures or market fluctuations. Ultimately, promoting diverse diets through urban agriculture reflects a holistic approach to food security, emphasizing the importance of varied and nutritionally rich food sources for the well-being of urban populations.

#### 3.2.1.3. Economic Advantage

Urban agriculture presents a significant economic advantage involving diverse income groups such as low, middle, stable, retirees, youth, and students. A study by Poulsen et al. (2015) reveals that stable-income households engage in urban agriculture not only for sustenance but also as hobbies or as an additional income source. This stands in contrast to low-income households, for whom urban agriculture serves as a vital means of daily consumption. The produced goods from urban agriculture can be effectively marketed and sold, contributing to income generation within the household. Particularly in developing countries where women often encounter employment constraints (Pearson et al., 2010), home-based urban farming emerges as a strategic approach for safeguarding cash income sources. Consequently, the sale of urban agriculture products plays a compelling role in addressing financial stability in metropolitan areas, offering an avenue for diverse income streams and mitigating social difficulties (Azunre et al., 2019).

Moreover, urban agriculture functions as a catalyst for agribusiness development within urban settings (Wiśniewska-Paluszak *et al.*, 2023). As households engage in the cultivation of crops, they contribute not only to local food markets but also to the broader agribusiness landscape. The surplus produce can be strategically marketed, creating opportunities for entrepreneurial ventures. This dual role of urban agriculture, addressing both household income needs and fostering agribusiness initiatives, indicates its various economic advantages in enhancing financial resilience and economic diversity within urban communities.

#### 3.2.1.4. Environmental Quality Improvement

Urban development is a complex phenomenon related to some significant environmental problems. Biodiversity, water cycle, and climate alteration are common in urban areas. Hence, urban agriculture contributes to a significant improvement in environmental issues. Urban agriculture, specifically microgreens, uses few fertilizers as an input (El-Nakhel *et al.*, 2021). The fertilizers, which are usually derived from animal manure or synthetically produced, can give rise to several greenhouse gas emissions and harm the environment (Davison & Cape, 2003). One of the common gases being emitted from agricultural practices is ammonia (Palys *et al.*, 2021) whereby its excessive release (generally within conventional farming) causes nitrogen pollution, leading to soil acidification (Ti *et al.*, 2019), leaves damage due to ammonia toxicity, and alteration of crops' metabolisms (Guthrie *et al.*, 2018). Reducing the use of fertilizers could thus solve the problems associated with greenhouse gas emissions.

Furthermore, urban agriculture may reduce the urban heat island (UHI) effects (Mohammad *et al.*, 2019). Waffle *et al.* (2017) defined the UHI as the increased temperature within urban areas but not in the neighboring provincial areas. As the development increases within the urban areas, the conventional vegetation regions will decrease as the surfaces are macadamized, paved, and covered with concrete buildings. Consequently, it will increase temperature due to decreased plant cover and evapotranspiration, severely elevating the UHI effects. Within the urban area in the semi-arid western region of India, it has been identified that nearly all urbanites are experiencing night-time warming effects (Pancholi *et al.*, 2018) resulting from the increased UHI intensity. However, urban agriculture activity on the roof areas of buildings can lower the UHI intensity. A study by Qiu *et al.* (2013) reveals that these rooftop agricultural activities have resulted in cooling effects (reduction in UHI intensity) and might provide energy consumption savings. Green roofs at Loutraki, Greece, and Singapore dropped 2.0 and 4.0 °C, respectively.

Moreover, urban agriculture, while susceptible to reducing food miles (Artmann & Sartison, 2018), holds promise in mitigating environmental impact, notably by reshaping spatial dynamics and fostering local food cultivation. As urban dwellers engage in nearby food production, the proximity of production facilities and markets reduces transport costs, leading to a tangible reduction in carbon footprint and polluting gas emissions (Pradhan *et al.*, 2020; Deelstra & Girardet, 2000). This localized approach enhances food security and aligns with sustainable practices, addressing ecological challenges associated with long-distance transportation. Urban agriculture emerges as a practical solution that meets immediate food needs and contributes to environmental quality improvement, promoting eco-friendly urban spaces and sustainable urban development.

#### 3.2.1.5. Green Space Enhancement

Urban agriculture is imperative in enhancing urban environments by creating green spaces. In rapidly urbanizing areas, the expansion of concrete jungles often leads to a reduction in natural landscapes. However, urban agriculture intervenes by transforming underutilized spaces into vibrant green areas. These cultivated spaces not only counteract the negative impacts of urbanization but also contribute significantly to the overall aesthetics of the urban landscape (Calheiros & Stefanakis, 2021). Greenery adds a visually appealing dimension to the cityscape, softening the harsh lines of buildings and providing a refreshing contrast to the concrete surroundings. Beyond their visual impact, these green spaces serve as important recreational areas, offering city dwellers a reprieve from the hustle of urban life. Moreover, creating green spaces through urban agriculture contributes to the holistic well-being of urban populations. Accessible and well-maintained green areas allow residents to engage in outdoor activities, fostering a healthier and more active lifestyle (Artmann *et al.*, 2020). These spaces become communal focal points, encouraging social interactions and community bonding. Thus, the benefits of urban agriculture extend beyond the immediate realms of food production, impacting the overall quality of life in urban settings through the thoughtful integration of green spaces into the urban fabric.

### 3.2.2. Challenges in urban agriculture: Implications for microgreen cultivation

As the necessity for urban agriculture grows amid global urbanization trends, acknowledging its potential for sustained urban development reveals specific challenges that particularly impact microgreens. First, the issue can arise involving limited access to productive factors, e.g., lack of financial capital (Houessou *et al.*, 2020). Even though microgreen cultivation can occur in non-conventional spaces like balconies, rooftops, and indoor areas, money still has problems. The beginning of the infrastructure and interest in the practices is a challenge for a beginner in urban agriculture. The individual must spend money to purchase basic urban farming needs such as seeds, compost soils, pots, and sprayers. The cost was hindering initial practice efforts, which has categorized financial constraints as alarming.

Besides, concerns persist regarding the safety and freshness of microgreens produced in urban agriculture settings (Jonck *et al.*, 2018; Gómez *et al.*, 2019). The pollution, mainly air pollution associated with the urban norm, was a health risk for microgreens. Crops produced in areas polluted by heavy metals (such as mercury, lead, and cadmium) or toxic chemicals (such as dioxins and polychlorinated biphenyls) are not suitable for human consumption (Margenat *et al.*, 2019). Heavy metals contamination associated primarily with the air, water, and soil can cause neurological and kidney damage (WHO, 2020). Furthermore, those mentioned toxic chemicals, usually derived from industrial by-products, can cause reproductive and developmental problems, damage the immune system, interfere with hormones, and cause cancer. In some severe cases, these food-borne diseases arise from chemical contamination and might result in long-lasting disability and death.

A reliable water supply is needed for urban vegetable production. However, not all places can provide safe and stable water at a low cost (Haldar *et al.*, 2021). Adequate access to fertilization and soil is also significant but may be too costly for some urban growers. Lastly, one of the most prevalent issues affecting urban agriculture is the stagnation of public policies that do not reflect existing social problems (Marçal *et al.*, 2021). Poorly planned policies may lack limitations, resulting in environmental and human rights problems (Tornaghi, 2017), ultimately impacting the sustainable growth of microgreens within urban agriculture.

### 3.2.2. Global Trends of Microgreen Agriculture

Emanating from San Francisco, United States, in the early 1980s, microgreens were introduced on the chef menus as a combination of its several species, giving rise to a colorful mixture of ingredients called "Rainbow Mixed". Today, microgreens have become one of the emerging functional foods of the twenty-first century but have yet to gain a global market (Venice, 2019). Having 515 million undernourished people recorded by the Food and Agriculture Organization (FAO) of the United Nations, a food-based appeal is one of the mechanisms that the organization proposed to cope with the dilemma (FAO, 2017). Nevertheless, the World Health Organization documented that 462 million people worldwide are underweight (WHO, 2020), with 52 million children languishing undernourishment. These growing trends are derived from several factors, such as lack of access to food, malnutrition, and poverty. Malnutrition involving hidden hunger is currently happening in developing countries, which caused the global microgreen market predicted within the forecast period (2020–2025) to increase in terms of its cumulative annual growth rate (CAGR) to 7.5% (Mordor Intelligence, 2020).

As time passed, due to the extensive nutritive contents, microgreens have deviated from food ingredients to become the components of cosmeceutical production. Microgreens can be further processed, yielding oils and components that can be used in the beauty business manufacturing (Chester, 2019). Two prominent compounds typically obtained from almost all microgreens are vitamins and micro-elements, which are essential in the cosmetic industry (Paradiso et al., 2018).

In 2019, the continent of North America emerged as a sizable market share mainly due to countries like the United States, Canada, and Mexico having extensive microgreens production. The microgreens market in the United States is expected to register a CAGR of 10.1% from 2020 to 2025 (Mordor Intelligence, 2020). The rising awareness of health amongst consumers within these countries has led individuals to eat a nutrient-rich diet, leading to indoor agricultural production (Specht *et al.*, 2016).

Microgreens are generally being cultivated by greenhouses, vertical farming, and hydroponics in the United States. With intensified urban farming practices, microgreen cultivators can yield microgreen production at a larger scale. The dissemination of greenhouses across the United States varies depending on the region. The Southern regions of the United States accounted for 71% and 59% of the Northeast for microgreens production in 2017 (GlobeNewswire, 2020). The common microgreens grown in the United States are amaranth, beets, cabbage, celery, cilantro, fennel, kale, mustard, radish, and sorrel.

### 3.2.3. Microgreen Agriculture in Asia

Microgreen cultivation in Japan is mainly being observed within the cities. The efforts are driven by the initiative of urbanites to transform the city into a forest city. Microgreens are commonly cultivated in rooftop gardens (Buehler & Junge, 2016). For example, all buildings in Tokyo must devote at least 20% of their rooftop to greenery (Irga *et al.*, 2017). Also, the Japanese philosophy prioritizes local food production and consumption (Kimura & Nishiyama, 2008), resulting in more effort being put forth by the people or regulators to develop microgreen production.

The development of microgreens is also significant in India (Yadav *et al.*, 2019). As part of functional food, these microgreens gradually become mutual, especially for vegans who desire to eat organic food and want a healthy, nutritious vegetarian diet (Fuente *et al.*, 2019). Nevertheless, the start of microgreen cultivation in India is considered affordable, partly contributing to the vast development of this microgreen cultivation project. Microgreens grown commercially in India are primarily marketed to hotels, restaurants, and cafes, where chefs are inspired to use them in various dishes. Coriander, fenugreek, fava beans, radish, mustard, chickpea, cilantro, basil, lettuce, kale, baby spinach, beet, pea shoots, and mung beans are the most frequently used microgreens in Indian cooking (React Green, 2020).

In recent years, urban agriculture has become the choice of people living in South Korea due to the severe air pollution, shrinking rural areas, and high-tech agricultural equipment. Since air pollution threatens outdoor activities, indoor agriculture activity, i.e., hydroponics, greenhouse, and vertical farming using LED. Not just an initiative of the citizens, it also receives support from the local government by partnering with several modern agriculture companies (Maresca, 2019). In Seoul, microgreens and other leafy greens are vertically farmed with LED, and hydroponic techniques have started to operate within the subway station. The same farm concept has been developed deep beneath mountains located in North Chungcheong as well (Doran & Pisa, 2019).

Hong Kong has recorded the growth of several aggrotech companies advocating the production of vegetables, including microgreens, mainly because they are genuinely dependent on food import, which accounts for 90% of the food supply (Lor, 2019). Microgreens production attracted its citizens, and a few renowned companies have been established to provide the essentials (seeds and various equipment) and consultation on farming methods.

### 3.2.4. Microgreen Agriculture in Southeast Asia

Even though Singapore appears to be one of the significant vegetable importers (95% of total vegetable consumption), the rooftops and buildings constructed in this city-state and island country can develop into urban farming sites (Kumar *et al.*, 2019). A plan for rooftop farming, including microgreens cultivation in public housing estates in Singapore, was put forward to fix food security (Astee & Kishnani, 2010) and reduce the footprint associated with food imports (Lehmann, 2014). The Singapore government has invested $60 million in the aggrotech business, making more modern agricultural production run (Tan, 2021). The enthusiasm of modern farmers and the government's strong support in constructing a new agricultural framework in Singapore can rejuvenate this agricultural economic sector, thus increasing agricultural products (including microgreens).

In Malaysia, microgreen cultivation is yet to develop like in other Asian countries. It was an emerging functional food that some entrepreneurs in the agro-based industry would like to introduce to Malaysian consumers. In Kuala Lumpur, producing microgreens takes less time to deliver fresh vegetables and reduce carbon footprints. Besides knowing the valuable nutrition of microgreens, these factors have become an attraction for consumers to purchase. In 2019, microgreens were introduced during culinary competitions at the Food and Hotel Malaysia (FHM) event (Dayangku, 2020). Consequently, microgreens were available in supermarkets like Aeon, Lotus, and Jaya Grocer in later years.

With 270 million people living in Indonesia, it is hard for local conventional agriculture to accommodate the demands for food products. Alternatively, some agro-entrepreneurs residing in Lombok, Bandung, and Jakarta have started importing microgreen seeds or purchasing from local seed producers to cultivate in the city areas (Redaksi, 2020). The most common way of cultivating microgreens in Indonesia is through greenhouses, hydroponics, and backyard farming. In addition, the recognition of the products is quite impressive, with market price reaching Rp. 850–2000 per gram (Unas, 2021). Most microgreen businesses are conducted on websites and social media (e.g., Facebook, Blogger), with few sold in giant hypermarkets in central cities.

### 3.3. Microgreens Agriculture and their Species

Sprouts, microgreens, and baby greens are at different stages of plant development, whereby they can be harvested and consumed at all these stages. When the seeds germinate, they appear as sprouts, followed by microgreens. Microgreens will further develop into baby greens, consequently growing into mature plants. Sprout is the first emergence of a plant after the seed has been germinated and grown for five to seven days (Riggio *et al.*, 2019). Sprout includes a stem and two leaves which are merely cotyledons rather than the true leaves. Unlike mature plants, sprouts do not require light as they cannot undergo photosynthesis, but they obtain energy and nutrients from the seeds. Since sprouts are harvested before they need soil to develop and stabilize, they are often grown in water only. Due to their frequent exposure to moisture, sprouts are more susceptible to microbial infections, foodborne bacteria, mold, and fungi than other stages of plants (Mostafidi *et al.*, 2020).

Microgreens are sprouts that have been left to grow for at least a week in an appropriate environment. Morphologically, microgreens contain a stem, and root system, more extensive than the sprout, and actual leaves (Choe *et al.*, 2018). Microgreens do not have their roots or the lower part of the stems harvested compared to the sprouts. Instead, the central stem is cut off, leaving a thin and soft stem with a few small leaves. Microgreens can take up to 2–3 weeks to grow with 1–3 inches of length (Ghoora *et al.*, 2020).

Microgreens are nutrient-dense, having four to six times more nutrients than their adult counterparts (Xiao *et al.*, 2012). It is also considered flavorful, typically concentrating on the flavors of its mature plant, and it has a variety of stem and leaf sizes, textures, and colors (Weber, 2017). Unlike sprouts that rely on the seeds' nutrients, microgreens are dependent entirely on inputs from their growing medium for nutrients and light for photosynthesis. Currently, there are studies focused on the potential of light-emitting diodes (LEDs) to replace natural sunlight in photosynthesis (Alfirai *et al.*, 2019; Samuolienė *et al.*, 2019; Zhang *et al.*, 2020).

Both sprouts and microgreens are condensed forms of full-grown crops. As they are still in the early stages of development, the plants have more vitamins and proteins than adult plants (Gioia & Santamaria, 2015). Since the sprouts grew smaller than the microgreens and have not fully consumed the accumulated resources in the seeds, the former has more of its original nutrients (Mir *et al.*, 2021). Microgreens, however, have more mass and growth than sprouts due to their ability to undergo photosynthesis, generating more nutrients and phytochemicals (Zhang *et al.*, 2020).

### 3.3.1. Cultivation of Microgreens Practices

Microgreens are easy to cultivate, they can be grown either outdoors (as in the garden bed or cultivated within the container) or placed indoors as long as there is access to sunlight. To enhance the germination of the microgreens, Kou *et al.* (2013) suggested the seeds need to be soaked in acidified water (pH 5.5–6.0) for 12 hours.

Many different varieties of seeds can be used in the cultivation of microgreens. Depending on the species, the seeds have unique flavors and are generally described as intense and condensed. It ranges from mild to spicy, mildly acidic, and salty. Even though the cultivation of microgreens does not relate to foodborne outbreaks, the systemic seed threat increased when the seeds were inspected for the microbiological quality criteria (Xiao *et al.*, 2015). Therefore, non-chemical treatments for seed surface sterilization and antimicrobial action suitable for the cultivation of organic microgreens should be implemented (Ding *et al.*, 2013).

Microgreens can be cultivated in various ways, with different media being used depending on the method, i.e., soil growing, soilless growing, and hydroponics growing. Cultivating microgreens in the soil is not preferred by most growers because it would be messy and costly to grow indoors. Instead, the soil is replaced by other media types, and the seedlings are supplied with additional nutrient solutions whenever necessary. Growing microgreens in a standard, sterile, loose, and soilless germination medium consisting of various organic and inorganic materials are on the rise (Rajan *et al.*, 2019). While the alternative growing media resemble the soil, fertilizers are required because they have a lower nutritional value. Examples of commonly used soil-free organic growing media are coconut coir, pine bark, rice hulls, and peat moss (Nwosisi & Nandwani, 2018). Inorganic additives, such as vermiculite and perlite, may be added to the organic soilless media (Singh *et al.*, 2019). The vermiculite helps to increase water and nutrient retention (Suvorov & Skurikhin, 2003), while perlite acts as a natural filtration system, allowing excess water to quickly drain away while retaining little moisture and nutrients due to its lower water holding capacity (WHC) feature (Kingston *et al.*, 2020). Thus, these inorganic additives may have beneficial outcomes for microgreens. The last type of soilless system is hydroponic (Palmitessa *et al.*, 2020), which involves growing the microgreens in a nutritionally water-based solution rather than soil, with fertilizers occasionally being supplied.

Microgreens are relatively easy to grow indoors and outdoors, but providing them with adequate nutrients such as fertilizer can be challenging. The fertilization of microgreens is similar to other vegetable crops. However, they required much knowledge about the form of fertilizer that provides the most benefits to microgreens. The ideal fertilizers for growing microgreens are mixed with dirt, water use, or top-dress. For the soilless growing method, Murphy *et al.* (2010) postulate that by utilizing pre-planting fertilization of the peat-lite (soilless growing medium) mixed with calcium nitrate at 2000 mg/L nitrogen (150 mL/L medium), and post-planting solution fertilization with 150 mg/L nitrogen, it could result in a substantial increase in beet microgreen yield.

After germination, most species of microgreens can be harvested after 7–14 days of seeding (Pinto *et al.*, 2015; Weber, 2017; Bhatt & Sharma, 2018), or as soon as the cotyledons are matured, and the first real leaves have appeared. Pea microgreens, however, may be harvested with multiple leaves after 10 days due to their faster growth rate (Michell *et al.*, 2020). Lafreniere (2020) mentioned that if the microgreens are sown after the optimal harvest period, there will be a slightly bitter and rough (fibrous) texture. Nevertheless, the yield would be lower if it were harvested too early. Most microgreen growers pull the microgreens up with one side and cut them down below to avoid the microgreens falling into the soil or soilless media and getting dirty. Since the exudate of the cut stem is nutrient-rich and may encourage microbial development, washing the crop as soon as possible after harvest is recommended, and chilled water can be used to obtain rapid post-harvest cooling of microgreens (Cantwell & Suslow, 2002).

One of the challenges associated with microgreen cultivation is the contamination of insect pests like aphids, thrips flies, and fungus gnats (Nolan, 2019). These pests can cause damage to the plants by feeding on their leaves or stems, and they can also spread diseases such as damping-off disease to microgreens. To control these pests, it is essential to check the plants daily for signs of infestation and promptly remove any infested plants. Natural pest control methods such as neem oil or bio-insecticidal soaps can be effective alternatives to chemical pesticides (Satisha, 2023). Good air circulation, appropriate lighting, proper watering, and adequate drainage are crucial factors in preventing future infestations (Mir *et al.*, 2022). Sterilizing soil and equipment, minimizing moisture levels, using disease-resistant seeds, and applying organic fungicides can also help keep microgreens healthy. By following these prevention and control techniques, microgreen growers can effectively manage insect pests and ensure the health and quality of their crops.

### 3.4. Species of Microgreens

Microgreens can be grown using different types of seeds, such as vegetables, herbs, and flowers, thus giving many varieties. Each species has its unique characteristics, including the color of stems following mature plants (Caracciolo *et al.*, 2020). Nevertheless, most of them are greenish. The phytomorphology of the microgreens may also be different in terms of the shape of true cotyledon leaves. Furthermore, microgreens often have a wide array of flavors, such as nutty, earthy, herb-like, spicy, astringent, and sweet (Xiao *et al.*, 2015).

The Brassicaceae, also known as Cruciferae, is a family of midsized but commercially important flowering plants grown worldwide. It comprises 300 genera and 1500 species, including several cruciferous vegetables and medicinal plants (Ramadan & Oraby, 2020). The Brassicaceae family does not only grow for mature vegetables. The oilseeds from the genus *Brassica*, such as *B. napus*, *B. rapa*, *B. juncea*, and *B.* carinata, account for 12% of the global edible vegetable oil production reported by the Food and Agriculture Corporate Statistical Database (FAOSTAT) (Šamec & Salopek-Sondi, 2019). The Brassicaceae vegetables are also harvested during their early stages, called Brassicaceae microgreens. A variety of plant stages of this family are being commercialized as these vegetables are known for their valuable nutritional and medicinal benefits, especially in lowering cardiovascular diseases (Baenas & Wagner, 2019), diabetes (Kumar et al., 2019), and neurodegenerative diseases (Ogunlade *et al.*, 2021).

The genus *Brassica* encompasses plants from the mustard and cabbage family. The two species that are widely associated with the genus *Brassica* are *B. oleracea* and *B. rapa*. The *B. oleracea* has an important place in human history, from prehistory to the present day. It is one of the economically important crops, vegetables, fodder, and ornamental and is characterized by various edible parts (Fidler *et al.*, 2021). It is rich in essential nutrients, including vitamin A (Mohanta et al., 2018), and vitamin C (Belbase & Bc, 2020). The *B. oleracea* encompasses cabbage, broccoli, kohlrabi, cauliflower, kai-lan, and kale. Aside from its mature counterparts, it has also been commercialized at the microgreen stages. The *B. rapa* is a plant species that grows in various widely cultivated forms and comprises Chinese cabbage, pak choy, mizuna, and turnip, including an oilseed (*Brassica rapa* subsp. *oleifera*). Their young leaves are considered leafy vegetables and can be consumed raw, while older ones are better cooked. Apart from their mature counterparts, they have been commercialized at the microgreen stages.

The genus *Eruca* from the Brassicaceae family encompasses flowering plants from the Mediterranean region. The plants of this genus can be both annual and biennial. Five species (i.e., *E. loncholoma*, *E. pinnatifida*, *E. sativa*, *E. setulosa*, and *E. vesicaria*) have been characterized under this genus (Bell & Wagstaff, 2019), which *E. vesicaria* ssp. *sativa* is typically associated with microgreens. The *E. vesicaria*, commonly known as arugula or rocket, is an edible leaf vegetable with a tangy and bitter taste, with a peppery aroma (Shubha *et al.*, 2019).

The Asteraceae, also known as Compositae, is a family of 600 genera with 23,000 species (Gao *et al.*, 2014), mainly made up of flowering plants. It is commonly referred to as a daisy, composite, or sunflower family. The most distinguishing feature of Asteraceae is their inflorescence, morphologically known as the several tiny flowers clustered in a flower head (capitulum) that form a false “flower” (Broholm *et al.*, 2014). Some vegetables of this family are economically important, namely chicory, lettuce, marigold, sunflower, radicchio, and endive. Besides, they are being harvested at the microgreens stage. The study conducted by Paradiso *et al.* (2018) indicated that the Asteraceae microgreens constitute a high level of carotenoids; therefore, the microgreens derived from this family are popular as the carotenoids are antioxidants that may prevent aging, cancers, and eye diseases (Tan & Norhaizan, 2019).

The genus *Helianthus* comprises 70 species of annual and perennial flowering plants belonging to the daisy family of Asteraceae. The common name “sunflower” generally denotes the popular annual species *H. annuus* which the round flower heads (capitula) combined with ligules resemble the Sun. The native Americans were among the first to cultivate *H. annuus* as a food source (Khurana & Singh, 2021). This species is a source of all kinds of healthy fiber and vitamin E (Kaur *et al.*, 2020). Today, the mature plants of this genus (except for its seeds) are not commonly eaten. Instead, its microgreens are among 21st-century foods (Choe *et al.*, 2018)

The genus *Lactuca*, commonly known as lettuce, includes at least 147 species located mainly in temperate Eurasia (Singhal *et al.*, 2018). The plants derived from the genus *Lactuca* are diverse, as they are annuals, biennials, perennials, and shrubs. Most *Lactuca* wild lettuces are xerophytic as they are adapted to dry habitats. However, some are in more humid areas (subtropical to tropical rainforests), such as the Central African mountains and Eastern Africa (Kaur *et al.*, 2019). Besides the mature counterparts, which have been widely consumed, they have also been marketed at the microgreens stage.

The Amaranthaceae, commonly known as amaranth, encompasses 175 genera and 2050 species (Heywood *et al.*, 2007). This family comprises herbs and subshrubs distributed in all parts of the world (Simpson, 2010). Some species from this family are vitally important to the economic sector, for instance, beets (*Beta vulgaris),* quinoa (*Chenopodium quinoa*), kañiwa (*Chenopodium pallidicaule*), amaranth (*Amaranthus cruentus*), and spinach (*Spinacia oleracea*). Additionally, there are several agricultural weeds in this family, such as mat amaranth (*Amaranthus graecizans*), spiny pigweed (*Amaranthus spinosus*), and redroot (*Amaranthus retroflexus*).

The genus *Beta* encompasses flowering plants in the family of Amaranthaceae. This genus *Beta* belongs to crops of significant economic value due to its storage roots, which can accumulate a large quantity of sucrose (Kwiatkowska *et al.*, 2019). It is estimated that around eight species have been characterized, consisting of annual, biennial, and perennial species. One of the renowned species derived from the genus *Beta* is *Beta vulgaris* subsp. *vulgaris* (bull's blood beet), which is mainly cultivated for sugar production but is also used as a source of bioethanol and animal foods (Dohm *et al.*, 2014). Aside from its mature counterpart, it has been commercialized as well in the microgreen stage.

The genus *Amaranthus* consists of 70–75 species, which are annual or short-lived perennial plants collectively called amaranths (Iamonica, 2020). Some species derived from the genus *Amaranthus* are grown in the form of leafy vegetables, pseudo-cereals, and ornamentals. *Amaranthus* varies in the color of its flowers, leaves, and stems, with striking pigments from the maroon to the crimson spectrum. The leaves of certain plants of the genus *Amaranthus* are also being eaten (e.g., red amaranth), making its micro-counterpart being sold on the market.

The Lamiaceae, also known as Labiatae, is a family of 236 genera and 6900–7200 species commonly known as mint, sage, or dead-nettle family. Tamokou *et al.* (2017) reported that the main genera in this family are *Salvia* (900 species), *Scutellaria* (360), *Stachys* (300), *Plectranthus* (300), *Hyptis* (280), *Teucrium* (250), *Vitex* (250), *Thymus* (220), and *Nepeta* (200). This family gives rise to many aromatic herbs used in cooking, such as thyme, oregano, basil, sage, lavender, rosemary, and hyssop. Moreover, several medicinal herbs are included in the family, e.g., wild dagga, bee balm, oriental St. John's wort, and catnip. Plants of the Lamiaceae family are propagated for commercialization and self-consumption. Since the reproduction of plants is not as complicated as that of families, it is considered the most widely distributed plant family, with the Mediterranean region being acknowledged as the distribution center (Kocabas & Karaman, 2001).

The genus *Thymus*, also called Thymes, encompasses approximately 350 species of aromatic perennial herbaceous plants and subshrubs in the family of Lamiaceae (Toujani *et al.*, 2018). These plants usually reside in temperate regions, particularly in Europe, North Africa, and Asia. Several members of the genus are grown as culinary herbs or ornamental plants. One of the famous is *T. vulgaris* known as common thyme. The microgreens derived from the genus

*Thymus* are commercialized as "micro-thyme". These microgreens are favored herbs amongst chefs due to features that can be used entirely and provide a fresh and earthy taste, enhancing the visual appeal of the dishes due to their green hue (Mulvihil, 2010).

The genus *Ocimum* encompasses aromatic annual and perennial herbs and shrubs of the family of Lamiaceae. The genus *Ocimum* is widely known for its genus of basil, a cooking herb (*O. basilicum*). Most culinary and ornamental basil cultivars of *O. basilicum* (Singletary, 2018), have several hybrids between the species such as Thai basil, Amazonian basil, holy basil, and lemon basil. In addition to their mature counterparts, they have also been commercialized at the microgreen stage.

Apoaceae, also known as Umbelliferae, encompasses 434 genera with 3700 species, predominantly aromatic flowering plants. Some vegetables from this family are commercially important, such as anise, carrot, celery, coriander, cumin, fennel, parsley, and sea holly (Ahmed, 2018). Besides the culinary ingredients, some of the species derived from this family are dangerous because of the phototoxic compounds in the plant tissues, such as giant hogweed, poison hemlock, and spotted cowbane (Kreidl *et al.*, 2020). Generally, the plants associated with this family are usually cultivated in cool-season gardens (Zhang *et al.*, 2019); otherwise, the plants are reluctant to grow. Hence, the edible plants of Apiaceae are recommended for gardening or companion planting.

The genus *Cuminum* entails four flowering plants in the family of Apiaceae. The most notable species within the genus is the *C. cyminum* (cumin). It is the source of cumin seeds, which are a popular spice in Mexican, and Indian cuisines. These tiny seeds attach to the thin leaves, giving a strong cumin flavour. Few studies indicated that cumin attains some significant iron percentage (Sabet & Mortazaeinezhad, 2018; Bromand *et al.*, 2020; Davoodi *et al.*, 2020), making its micro-counterparts demanded from the consumers and being commercialized.

The genus *Foeniculum* comprises flowering plants in the carrot family, including the commonly cultivated fennel (*F. vulgare*). Fennel is renowned as an essential medicinal and aromatic plant utilized to treat gastrointestinal and respiratory disorders (Mihats *et al.*, 2017; Chen *et al.*, 2020). Its seeds are used as flavourers in pastries, meat, and fish dishes. Lastly, it has also been commercialized in the form of microgreens.

### 3.5. Essential Nutrients of Microgreens

Plants, including microgreens, rely on over 14 mineral elements for optimal nutrition, impacting plant growth and crop yields. White and Brown (2010) classify plant nutrition into primary, secondary, and tertiary nutrients. Macronutrients, such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and potassium (K), are crucial in substantial quantities. Micronutrients, including calcium (Ca), magnesium (Mg), and sulfur (S), are required in smaller amounts. At the same time, trace elements like iron (Fe), molybdenum (Mo), boron (B), copper (Cu), manganese (Mn), sodium (Na), zinc (Zn), nickel (Ni), chlorine (Cl), cobalt (Co), silicon (Si), vanadium (V), and selenium (Se) are essential in minute quantities.

Nitrogen, potassium, and phosphorus are vital for plants in significant amounts Nitrogen contributes to chlorophyll, amino acids, ATP, DNA, and RNA formation (Pramanik & Bera, 2013). Potassium regulates physiological processes like carbon dioxide absorption, photosynthesis, and osmoregulation (Ahanger *et al.*, 2017; Jha & Subramanian, 2016; Andrés et al., 2014; Ramu *et al.*, 2006). Phosphorus is essential for seed germination, and root development, and is a critical component of ATP, ADP, genes, and chromosomes (Toledo *et al.*, 2011). Secondary macronutrients, i.e., calcium, magnesium, and sulfur, play essential roles in crop production, cell wall formation, and metabolic functions. Calcium is a second messenger in response to various stresses (Thor, 2019; Reid *et al.*, 1995), magnesium is central to chlorophyll as well as needed for protein and nucleic acid synthesis (Chen *et al.*, 2018; Wang *et al.*, 2017). Lastly, sulfur is vital for proteins, enzymes, vitamins, and chlorophyll (Ördög, 2011). Tertiary nutrients, which are trace elements like boron, copper, iron, manganese, molybdenum, and zinc, are indispensable in minute quantities, influencing flowering, photosynthesis, enzymatic processes, and various metabolic roles in plants (Alejandro et al., 2020; Karademir & Karademir, 2020; Kandoliya et al., 2018; Kovács et al., 2015; Okmen et al., 2011; Kim *et al.*, 2001).

### 3.5.1. Nutritional Composition of Microgreens Compared to Macrogreens

A study conducted by Pinto *et al.* (2015) shows that not all nutritional constituents possessed by microgreens are higher than those in macrogreens (their mature counterparts). Their research, which experimented with lettuce (*Lactuca sativa*), shows that mature lettuces exhibited prominently higher nitrogen, phosphorus, and potassium content than microgreens. However, most of their nutritional components, such as calcium, iron, manganese, zinc, selenium, and molybdenum, were present extensively at higher levels in microgreens as opposed to macrogreens. Nevertheless, research carried out by Waterland *et al.* (2017) revealed that microgreens of three cultivars of kale, namely dwarf blue curled kale (*B. oleracea* var. *sabellica*), red Russian kale (*B. napus*), and scarlet kale (*B. oleracea* var. *acephala*) have a higher concentration of nutrients as opposed to their mature counterparts. The nutrients that were being assayed are derived from both macronutrients (potassium, calcium, magnesium, and phosphorus) and micronutrients (sodium, iron, manganese, zinc, and copper).

## 3.6. Secondary Metabolite Profiles from Microgreens

Several studies have revealed that microgreens are considered nutritious foods due to their elevated amount of secondary metabolite profiles than their mature counterparts (Kyriacou *et al.*, 2016). Barrios-González (2018) defined secondary metabolites as chemical compounds with diverse and complex chemical compositions produced by plants that are not explicitly required during normal development. These non-nutrient secondary metabolites (also known as phytochemicals) are the low-molecular-weight synthesized *de novo* or extant precursors, typically mediate ecological relationships that can provide the plants with a selective advantage in elevating its survivability upon confronting difficulties (Tiwari & Rana, 2015).

In microgreens, the high concentration of secondary metabolites is the cause of high endurance and resilience to any potential stress during the early stages of development. Technically, every plant typically synthesizes secondary metabolites during their stress condition, acting as antibacterial, antiviral, and antifungal agents (Wink, 1999). Some of these phytochemicals are well-known and have been reviewed. It is noteworthy that phenolics account for over 8000 broadly and differentially dispersed entities (Cartea *et al.*, 2011), and glycosylates are represented by at least 137 different structures (Blažević *et al.*, 2020). Different microgreens have different metabolites with various concentrations across the species. Examples of the secondary metabolite profiles of a few microgreen species are displayed in Table 1.

**Table 1.** Selected microgreen species and their main secondary metabolites.

| Microgreen | Main secondary metabolites | Reference(s) |
|---|---|---|
| Broccoli (*Brassica oleracea* var. *italica*) | Quercetin, kaempferol, chlorogenic, sinapic, glucoraphanin, glucoiberin, glucoraphenin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, neoglucobrassicin, isothiocyanates, sulphoraphane, iberin, and indole-3-carbinol | Baenas *et al.* (2017) |
| Kale (*Brassica oleracea* var. *acephala*) | Quercetin, cyanidin, chlorogenic, ferulic acids, glucoraphanin, glucoiberin, gluconapin, gluconasturtin, progoitrin, gluconapin, gluconapoleiferin, sinigrin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, and neoglucobrassicin | Jeon *et al.* (2018) |
| Radish (*Raphanus sativus* L.) | Quercetin, ferulic, caffeic, *p*-coumaric acids, glucoraphenin, dehydroerucin, glucobrassicin, 4-methoxyglucobrassicin, isothiocyanates, sulforaphene, sulforaphane, and indole-3-carbinol | Li & Zhu (2019) |
| Pak choi (*Brassica rapa* var. *chinensis)* | Kaempferol, quercetin, isorhamnetin glucosides, ferulic, sinapic, caffeic, *p*-coumaric acids, gluconapin, glucoalyssin, gluconasturtin, progoitrin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, and neoglucobrassicin | Jeon *et al.* (2018)<br>Liang et al. (2018) |
| Lettuce (*Lactuca sativa*) | Ascorbic acid, β-carotene, phenolic acids, isohamnetin, quercetin, epicatechin, mycertin, anthocyanin | Mampholo *et al.* (2016) |
| Cilantro (*Coriandrum sativum*) | Apigenin-7-*O*-glucoside, chlorogenic acid, dicaffeoylquinic acid, ferulic acid, feruloyl quinic acid, kaempferol, luteolin, quercetin, rosmarinic acid, and rutin | Kyriacou *et al.* (2019) |
| Basil (*Ocimum basilicum*) | Caffeic acid, chicoric acid, quercetin, rosmarinic acid, salvianolic acid, lithospermic acid | Majdi *et al.* (2020) |

### 3.6.1. Terpenes

Terpenes are aromatic compounds abundant in nature and are made from isoprene units with the molecular formula $C_5H_8$, therefore, all terpenes have the same basic formula $(C_5H_8)_n$ where n is the number of associated isoprene units. Terpenes can be characterized according to their order of subunits, namely hemiterpenes, monoterpenes, sesquiterpenes, diterpenes, triterpenes, tetraterpenes, and polyterpenes (Paduch *et al.*, 2007). They are a vast and diversified group of hydrocarbons produced by a variety of flora, which is responsible for the scent of most plants. The functions of the terpenes in plants are generally described as attractants or repellents, info-chemicals (Theis & Lerdau, 2003), and protective shields against herbivores (ruminants and insects) and pathogens (Wittstock & Gershenzon, 2002).

One of the most commonly studied terpenes on microgreens is carotenoids. Carotenoids are essential fat-soluble antioxidants with many functions related to human health, mainly responsible for scavenging free radicals and protecting cellular membranes. Carotenoids are not synthesized by humans but rather should be consumed through foods or supplements. Examples of carotenoids found in human blood samples are β-carotene, lutein, and zeaxanthin (Johra et al., 2020). The β-carotene is a natural precursor of Vitamin A (retinol) derived from some fruits and vegetables (including microgreens) that may have chemopreventive (Saini *et al.*, 2020) and antineoplastic activities (Jain *et al.*, 2018). Chemopreventive activities refer to the capacity of β-carotene, which functions in neutralizing the free radicals. The antineoplastics activities of β-carotene imply this compound's ability to eliminate early-stage tumor cells by inducing cell differentiation and apoptosis. Other benefits of β-carotene mentioned by Rouamba *et al.* (2018) encompass lowering cancer and heart disease chances, improving osteoarthritis, Alzheimer's disease, and cystic fibrosis, healing stomach ulcers, and protecting skin from aging.

Furthermore, lutein and zeaxanthin, mainly obtained from green leafy vegetables and orange-yellow-hued fruits, are characterized as xanthophyll carotenoids. These compounds are potent antioxidants highly concentrated in the human retina, particularly the macula region (Li *et al.*, 2020), often called macula pigments. Their responsibility in the macula region is to make sure the eyes are being protected from harmful free radicals. Therefore, decreasing these antioxidants over time can be detrimental to eye health, i.e., cataract formation, and age-related macular degeneration (AMD) (Roberts & Dennison, 2015). However, consuming carotenoid-rich foods (such as microgreens) may help prevent those diseases. A study conducted by Xiao *et al.* (2012) revealed that microgreens such as red sorrel, red cabbage, cilantro, pepper cress, garnet amaranth, wasabi, and green basil yielded a high amount of β-carotene in milligrams over 100 g their fresh weight (FW). In comparison, lutein and zeaxanthin have been concentrated in milligrams over 100 g fresh weight (FW) of cilantro, red sorrel, red cabbage, and green amaranth microgreens fresh weight (Table 2).

**Table 2.** Concentration of β-carotene, lutein, and zeaxanthin in microgreens*.

| Microgreen | β-Carotene concentration (mg/100 g FW) | Lutein and zeaxanthin concentration (mg/100 g FW) |
|---|---|---|
| Arugula | 7.5 ± 0.4 | 5.4 ± 0.2 |
| Bull's blood beet | 5.3 ± 0.8 | 4.3 ± 0.7 |

| | | |
|---|---|---|
| Celery | 5.6 ± 0.1 | 5.0 ± 0.1 |
| China rose radish | 5.4 ± 0.5 | 4.9 ± 0.4 |
| Cilantro | 11.7 ± 1.1 | 10.1 ± 0.3 |
| Garnet amaranth | 8.6 ± 0.3 | 8.4 ± 0.1 |
| Golden pea tendrils | 0.6 ± 0.0 | 2.7 ± 0.0 |
| Green basil | 8.4 ± 0.4 | 6.6 ± 0.3 |
| Green daikon radish | 6.1 ± 0.1 | 4.5 ± 0.1 |
| Magenta spinach | 5.3 ± 0.3 | 3.2 ± 0.2 |
| Mizuna | 7.6 ± 0.4 | 5.2 ± 0.3 |
| Opal basil | 6.1 ± 0.4 | 5.3 ± 0.3 |
| Opal radish | 6.3 ± 1.0 | 5.5 ± 0.9 |
| Pea tendrils | 8.2 ± 1.1 | 7.3 ± 1.2 |
| Peppercress | 11.1 ± 0.6 | 7.7 ± 0.4 |
| Popcorn shoots | 0.6 ± 0.1 | 1.3 ± 0.1 |
| Purple kohlrabi | 5.7 ± 0.2 | 4.0 ± 0.1 |
| Purple mustard | 5.6 ± 0.4 | 6.4 ± 1.9 |
| Red beet | 7.7 ± 0.1 | 5.5 ± 0.0 |
| Red cabbage | 11.5 ± 1.2 | 8.6 ± 1.0 |
| Red mustard | 6.5 ± 0.4 | 4.9 ± 0.3 |
| Red orach | 6.3 ± 0.3 | 3.9 ± 0.2 |
| Red sorrel | 12.1 ± 0.6 | 8.8 ± 0.2 |
| Sorrel | 5.2 ± 1.0 | 4.2 ± 0.8 |

| | | |
|---|---|---|
| Wasabi | 8.5 ± 0.2 | 6.6 ± 0.3 |

* Adapted from Xiao *et al.* (2012)

### 3.6.2. Polyphenols

Polyphenols are among the most abundant and commonly occurring secondary metabolite profiles in the plant kingdom, with more than 8,000 phenolic structures being recognized (Amaral *et al.*, 2021). Polyphenols can be classified in several ways; however, the most common is based on the chemical structure. Thus, polyphenols can be divided into two main categories, which are flavonoids and non-flavonoids. Flavonoids can be further classified into flavonols, flavones, isoflavones, flavonols, anthocyanidins, and flavanones. In contrast, non-flavonoids comprise phenolic acids, resveratrol, lignans, and tannins. The human health-related functions of two classes of polyphenols are detailed in Table 3.

**Table 3:** Reported functions of polyphenols related to human health.

| **Polyphenol** | | **Function(s)** | **Reference** |
|---|---|---|---|
| Flavonoid | Flavanol | Modulate metabolism and respiration (e.g., maximum $O_2$ absorption, $O_2$ exercise cost, and energy expenditure), and reduce oxidative stress and inflammation. | Al-Dashti *et al.* (2018) |
| | Flavone | Suppress adipogenesis, modulate immune responses in fat tissues, and reduce obesity-related inflammation. | Sudhakaran & Doseff (2020) |
| | Isoflavone | Improve certain aspects of cognition (e.g., mental flexibility and planning). | Roozbeh *et al.* (2018) |

| | | | |
|---|---|---|---|
| | Flavonol | Exert cardioprotection through specific mechanisms, mainly by inhibiting the selected kinase signaling pathways resulting from, or in addition to, the exertion of antioxidant activity. | Woodman *et al.* (2018) |
| | Anthocyanidin | Lower the risk for cardiovascular and coronary heart disease. | Vendrame & Klimis-Zacas (2019) |
| | Flavanone | Exert beneficial effects on intestinal barrier function and gastrointestinal inflammation. | Stevens *et al.* (2019) |
| Non-flavonoids | Phenolic acid | Improve cardiovascular health through reduced blood pressure and greatly improving endothelial function | Bento-Silva *et al.* (2020) |
| | Resveratrol | Inhibit adipogenesis, increase lipid mobilization in adipose tissue, and improve insulin sensitivity. | Springer & Moco (2019) |
| | Lignan | Reduce radical production by scavenging it, | Ugartondo *et al.* (2008) |

| | | | |
|---|---|---|---|
| | | and stabilise the reactions caused by $O_2$ and its radical species. | |
| | Tannin | Prevent oxidative stress-related diseases (e.g., cardiovascular disease, cancer, and osteoporosis). | Szczurek (2021) |

Tomas *et al.* (2021) mentioned that quantitative phenolic contents observed could vary across species of microgreens. In their studies, purple radish microgreens contained the highest concentration of phenolic compounds (4736.6 ± 11.6 mg GAE/100 g DW), followed by red cabbage (3461.0 ± 8.0 mg GAE/100 g DW), kohlrabi (3027.1 ± 4.7 mg GAE/100 g DW), and kale microgreens (2798.6 ± 4.7 mg GAE/100 g DW), as summarised in Table 4. However, the study performed by Fuente et al. (2019) indicated a significant difference in terms of TPC of purple radish and kale microgreens, with 2111.2 and 2415.9 mg GAE/100 g DW, respectively.

**Table 4.** Reported total phenolic content of selected microgreens.

| Microgreen | Total phenolic content (mg GAE/100 g DW) | Reference |
|---|---|---|
| **Kale** | 2798.6 ± 4.7 | Tomas *et al.* (2021) |
| | 2416.0 ± 109.3 | Fuente *et al.* (2019) |
| **Red cabbage** | 3461.0 ± 8.0 | Tomas *et al.* (2021) |
| **Kohlrabi** | 3027.1 ± 4.7 | Tomas *et al.* (2021) |
| **Purple radish** | 4736.6 ± 11.6 | Tomas *et al.* (2021) |
| | 2111.2 ± 132.8 | Fuente *et al.* (2019) |

### 3.6.3. Sulfur-Containing Compounds

Organo-sulfur compounds are generally found in cruciferous vegetables such as broccoli, cauliflower, Brussels sprouts, garlic, and onion. These compounds are frequently involved in various cellular defense mechanisms and usually originate from two sub-classes, namely glucosinolates and alliins (S-allyl cysteine sulfoxide). Glucosinolates precisely respond to environmental stimuli and carry out signal transduction at the beginning of the plant's defense mechanism (Singh, 2017). As important as its role in the plant system, it contributes beneficial effects for humans as well. Epidemiological data support the possibility that glucosinolates decomposition products derived from *Brassica* vegetables are anticarcinogens, particularly in the gastrointestinal tract and lungs (Prieto *et al.*, 2019). Whereas alliin, a non-protein amino acid, can kill the bacteria through the gas phase after being activated by the enzyme alliinase yielding allicin (Leontiev *et al.*, 2018). In human health, allicin can enhance the immune system, lower cholesterol levels in the liver, and detoxify carcinogens (Augusti *et al.*, 2012).

Glucosinolates have a high potential in maintaining good health, leading to extensive research being conducted to determine its availability. It is highly concentrated in Brassicaceae vegetables and seedlings (Samuolienė *et al.*, 2019). Even though its concentration varied on the organs and developmental stages of certain plants, Brown *et al.* (2003) mentioned that the glucosinolates concentrate at their peak in young leaves, likewise in the developmental stage of microgreens. A study conducted by Ku *et al.* (2014) indicated that glucobrassicin (22.4 μmol/g DW) had been found concentrated in the dry apical tissue of kale (*B. oleracea* var. *sabellica*), followed by glucoiberin (9.62 μmol/g DW) and neoglucobrassicin (6.01 μmol/g DW).

Other total glucosinolates content (TGC) studies on commercially grown microgreens conducted by Xiao *et al.* (2012) postulate that Chinese rose radish microgreens (535.5 ± 26.3 μmol/100g FW) constituted the highest glucosinolates concentration, followed by red komatasuna (397.1 ± 34.3 μmol/100g FW), red radish (393.0 ± 7.5 μmol/100g FW), tatsoi microgreens (377.8 ± 23.2 μmol/100g FW), and others.

### 3.6.4. Secondary Metabolite Profiles of Microgreens Compared to Macrogreens

Studies conducted by Xiao *et al.* (2012) raised a protruding conclusion for secondary metabolite concentrations within microgreens. When evaluating the content of several secondary metabolites in microgreens, namely ascorbic acid, α-tocopherol, phylloquinone, β-carotene, lutein, zeaxanthin, and violaxanthin, they discovered various concentrations across the species. Interestingly, the results (Table 5) revealed that the phytochemicals concentration condensed in some tiny seedlings (microgreens) were much higher than their mature counterparts. Even though the data of the macrogreens are not obtained from the same assayed, it was provided from reliable sources; the United States Department of Agriculture (USDA) national nutrient database, and previous research studies; garnet amaranth (Punia *et al.*, 2004), red cabbage (Podsedek *et al.*, 2006; Singh *et al.*, 2006), and cilantro (Kobori *et al.*, 2008).

**Table 5.** Different phytochemicals concentration of several species of microgreens as compared to their macrogreens.*

| Phytochemical | Species | Concentration | | Reference |
|---|---|---|---|---|
| | | Microgreen | Macrogreen | |
| Phylloquinone | Garnet amaranth | 4.09 μg/g FW | 1.14 μg/g FW | USDA (2012) |
| | Basil | 3.20 μg/g FW | 0.41 μg/g FW | USDA (2012) |
| | Red cabbage | 2.77 μg/g FW | 0.04 μg/g FW | USDA (2012) |

| | | | | |
|---|---|---|---|---|
| Ascorbic acid | Red cabbage | 147.0 mg/100 g FW | 57.0 mg/100 g FW | USDA (2012) |
| | Garnet amaranth | 131.6 mg/100 g FW | 45.3 mg/100 g FW | Punia *et al.* (2004) |
| β-Carotene | Red cabbage | 11.5 mg/100 g FW | 0.044 mg/100 g FW | Singh *et al.* (2006) |
| | Cilantro | 11.7 mg/100 g FW | 3.90 mg/100 g FW | USDA (2012) |
| Lutein and zeaxanthin | Red cabbage | 8.6 mg/100 g FW | 0.3 mg/100 g FW | USDA (2012) |
| | Cilantro | 10.1 mg/100 g FW | 0.9 mg/100 g FW | USDA |
| Violaxanthin | Cilantro | 7.7 mg/100 g FW | 1.4 mg/100 g FW | Kobori *et al.* (2008) |
| α-Tocopherol | Red cabbage | 24.1 mg/100 g FW | 0.06 mg/100 g FW | Podsędek *et al.* (2006) |

* Adapted from Xiao et al. (2012)

First and foremost, the difference between the phylloquinone concentration (µg) was determined per microgreens and macrogreens of mature amaranth, basil, and red cabbage freight weight (g FW). The phylloquinone concentration of garnet amaranth microgreens (4.09 µg/g FW) was 3.6-fold higher than its mature counterpart (1.14 µg/g FW). Basil microgreens contained an average of 3.20 µg/g FW, approximately 8-fold more than the value (0.41 µg/g FW) of its macrogreens. Red cabbage microgreens (2.77 µg/g FW) had much higher phylloquinone than mature red cabbage (0.04 µg/g FW).

Besides, ascorbic acid concentrations in red cabbage and garnet amaranths were 147.0 and 131.6 mg/100 g FW, respectively, which were higher than the value for their corresponding macrogreens (57.0 and 45.3 mg/100 g FW, respectively). Compared with the β-carotene concentration of the mature red cabbage (0.044 mg/100 g FW), and cilantro (3.90 mg/100 g FW), their microgreens contained 26-, and 3-fold more β-carotene (11.5 and 11.7 mg/100 g FW, respectively). Furthermore, mature cilantro and red cabbage exhibited lutein/zeaxanthin concentrations of 0.9 and 0.3 mg/100 g FW, respectively, their microgreen counterparts, whose lutein/zeaxanthin concentrations were 11.2 and 28.6 times more significant. Next, the maximum concentration of violaxanthin in cilantro microgreens (7.7 mg/100 g FW) was more than five times higher than the macro-cilantro (1.4 mg/100 g FW). Lastly, the α-tocopherol content of red cabbage microgreens (24.1 mg/100 g FW) was more than 40 times its mature equivalent (0.06 mg/100 g FW).

Additionally, Ghoora *et al.* (2020) revealed the comparison of phytochemicals amount consisting of ascorbic acid, α-tocopherol, and β-carotene as opposed to their macrogreens, cultivated under similar conditions. The ascorbic acid concentration (mg/100 g) of roselle, fenugreek, and spinach microgreens possessed 119, 120, and 127%, respectively, significantly ($p \leq 0.05$) higher as compared to their macrogreens. The trend was also similar regarding the α-tocopherol concentration (mg/100 g) on those microgreens compared to their mature greens, in which microgreens were indicated to have more α-tocopherol amount. However, the comparison of β-carotene concentration (mg/100 g) showed that mature forms of those vegetables had a higher concentration of β-carotene. The mature fenugreek and roselle were shown to contain a significantly higher amount of β-carotene, while mature spinach was slightly higher than their respective microgreens.

## 3.7. Health Perspectives of Microgreens

### 3.7.1. Biological Activities of Microgreens

Recently, there has been an emerging body of literature indicating that edible microgreens are an excellent source of bioactive compounds. As mentioned, microgreens have an intense concentration of bioactive compounds compared to their mature counterparts, which can significantly boost natural defense systems and reduce the risk of chronic diseases when consumed regularly (Moreira-Rodríguez *et al.*, 2017). Bioactive compounds are other nutritious ingredients of foods that can modulate physiological processes and provide well-being benefits through their biological activities.

Various biological activities are exerted by the bioactive compounds from microgreens (Table 6), namely antioxidant, anti-cancer, anti-proliferative, anti-tyrosinase, anti-inflammatory, anti-diabetic, anti-obesity, and antimicrobial activities. Amongst all these biological activities, antioxidant activity is widely getting attention from researchers due to its most effective metabolic regulation and potential health benefits. In addition, antimicrobial activity has been reviewed thoroughly due to its impressive effects, i.e., adequate protection against disease transmission. Liu *et al.* (2017) stated that most of the matured herbs like clove, oregano, thyme, cinnamon, and cumin have splendid antimicrobial activity making their microgreens have a higher potential of exerting the same effects, with a probability of having more substantial results due to their concentrated sources of antimicrobial compounds. In the current review, two prominent biological activities are discussed, i.e., antioxidant and antimicrobial.

**Table 6.** Reported biological activities of selected microgreens and respective bioactive compounds.

| Microgreen | Bioactive compound(s) | Biological activity | Reference |
|---|---|---|---|
| Broccoli (*Brassica oleracea* L. var. *italica*) | Ascorbic acid and α-tocopherol | Antioxidant activity by inhibiting the activity of prooxidant enzymes and enhancing the activation of antioxidant enzymes | Le *et al.* (2020) |
| Radish (*Raphanus sativus*) | Glucosinolates | Anti-proliferative effect by inducing apoptosis and arresting cell cycle progression | López-García *et al.* (2020) |
| Green mustard (*Brassica juncea* L. *Czern*) | Isothiocyanates | Anti-cancer activity by inhibiting histone deacetylase, and Bcl-2 protein expression | Saengha *et. al* (2021) |

| | | | |
|---|---|---|---|
| Red cabbage (*Brassica oleracea* var. *capitata* f. *rubra*) | Polyphenols and glucosinolates | Anti-diabetic and anti-obesity activity by inhibiting Diacylglycerol *O*-Acyltransferase 1 (DGAT1) | Huang *et al.* (2016) |
| | Kaempferol, quercetin, and resveratrol | Anti-inflammatory activity by suppressing cyclooxygenase-2 enzyme activity | Choe *et al.* (2018) |
| Kale (*Brassica oleracea* var. *sabellica*) | Tyrosol and flavonoids | Anti-tyrosinase activity by inhibiting tyrosinase enzymes | Tomas *et al.* (2021) |
| Fenugreek (*Trigonella feonum-graecum* L.) | Diosgenin | Anti-neoplastic activity by inhibiting necrosis factor NF-kappa B-regulated gene expression, and enhancing apoptosis | Olaiya & Soetan (2014) |
| Green peas (*Pisum sativum*) | Ascorbic acid and β-carotene | Antioxidant activity | Senevirathne *et al.* (2019) |

#### 3.7.1.1. Antioxidant Activity of Microgreens

Atasoy *et al.* (2019) defined antioxidant activity as an ability to obstruct the propagation stage in oxidative chain reactions. This biological activity is an extensive example of functional benefits that microgreens can deliver with their higher amount of antioxidants concentrated in them. These antioxidants refer to stable molecules that transfer their electrons to free radicals, neutralizing, and reducing the harmful ability of free radicals (Lobo *et al.*, 2010).

There are two forms of antioxidants, namely primary and secondary antioxidants, which have distinct functions. The former directly scavenges free radicals by donating electrons in the system, while the latter indirectly averts the establishment of free radicals through quenching chain-initiating catalysts (Fenton's reaction) (Rice-Evans & Diplock, 1993). The free radicals in the form of reactive oxygen species (ROS) could trigger oxidative damage to biological molecules, which can cause homeostatic disruption and cell damage (Young & Woodside, 2001). ROS is generally synthesized by several leucocytes (e.g., monocytes and neutrophils), endothelial cells, and some enzymes such as xanthine oxidases, lipoxygenases, and nitric oxide syntheses (Bardaweel *et al.*, 2018).

Besides, antioxidants can be characterized by natural and synthetic compounds. Natural antioxidants, such as flavones, flavonoids, and carotenoids are generally found in microgreens as well. Even though most of the studies are assessing the mature counterparts (macrogreens), Xiao *et al.* (2019) suggested that almost all microgreens have four to six times more nutrients than the mature counterparts of the same plant. Therefore, it is possible to indicate that the antioxidants might be present in the seedlings as well.

In contrast, synthetic antioxidants are used as a substitute for natural ones, primarily in foods and medicine, especially those containing oils and fats that need protection against oxidation (Sindhi *et al.*, 2013). There are several synthetic antioxidants, for instance, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tert-butyl hydroquinone (TBHQ), propyl gallate (PG), octyl gallate (OG), nordihydroguaiaretic acid (NDGA), and 4-hexylresorcinol (Lourenço *et al.*, 2019). Nevertheless, synthetic antioxidants are claimed to have similar health benefits as natural antioxidants. Research studies found that the usage of synthetic antioxidants in high doses will promptly get a severe impact, e.g., DNA damage, and induce premature aging in a long-term intake (Kornienko *et al.*, 2019). It has already been established that BHA and BHT cause harmful effects on the liver and carcinogenicity in animal studies (Saad *et al.*, 2007). Besides, a study suggested that PG may enhance testicular dysfunction in Leydig and Sertoli cells through the suppression of steroidogenesis and cell viability (Ham *et al.*, 2019), leading to male infertility.

#### 3.7.1.2. Antimicrobial Activity of Microgreens

Elmogahzy (2019) defined antimicrobial activity as an activity of a compound that prohibits microorganisms from growing, preventing the development of microbial colonies, and possibly killing microbes. The potency of antimicrobial agents is indicated by the antimicrobial activity per mg/µg against either Gram-positive or Gram-negative bacteria. The antimicrobial activity can be investigated in several classifications, namely minimal inhibitory concentration (MIC), minimal bactericidal concentration (MBC), and minimum antibiotic concentration (MAC). The MIC indicates the minimum amount of a drug required to inhibit the growth of the bacteria *in vitro*, and MBC refers to the minimum amount of a drug required to kill bacteria *in vitro*, whereby the ratio of MBC/MIC is calculated to establish the microbicidal or micro biostatic properties of the agents (Shamlan *et al.*, 2020). Lastly, MAC refers to the effects of subinhibitory antimicrobial concentration on bacteria.

A natural or synthetic material that destroys or prevents the growth of microbes such as bacteria, fungi, and algae is known as an antimicrobial agent. While synthetic antimicrobial agents have been accepted in several countries, many researchers are still interested in using natural compounds obtained from microbes, animals, or plants (Gyawali & Ibrahim, 2014). The use of antimicrobial agents derived from natural resources such as microgreens has shown a reduction in the disease rate caused by microbiological pathogens (Arshad & Batool, 2017). Secondary metabolites derived from plants and vegetables have been investigated in many studies and are known to possess antimicrobial activity (Medema *et al.*, 2011).

Alkaloids have been shown to exhibit antimicrobial activity. Several studies suggested that alkaloids may play a significant role in the treatment of a variety of infectious diseases such as malaria (Abdullahi *et al.*, 2020), tuberculosis (Mishra *et al.*, 2017), and influenza, by inhibiting ethyl-pyruvate formation which is thought to be a form of antimicrobial action (Moradi et al., 2017).

Besides, several antimicrobial activities derived from the sulfur-containing compounds from plants have been published in the literature. For example, allicin, dialkyl-sulfides, and isothiocyanates are amongst renowned sulfur-containing compounds obtained from microgreens (Lee *et al.*, 2012) that have exerted antimicrobial activity against both Gram-positive (*Staphylococcus aureus* and *Bacillus subtilis*) and Gram-negative bacteria (*Salmonella typhimurium* and *Escherichia coli*) (Sobolewska *et al.*, 2015). Nevertheless, a study conducted by Asili *et al.* (2009) reveals that those plants that constitute a high amount of polysulphides (also available in microgreens) are competent in having an extensive range of antimicrobial activity. The clinical trial conducted indicates the reduction of the gastric bacterial colony and gastritis attenuation in *Helicobacter pylori*-infected mice and patients upon consumption of sulforaphane-rich broccoli seedlings (Yanaka *et al.*, 2009).

### 3.7.1.3. Antiproliferative Activity of Microgreens

Antiproliferative refers to the capability of a substance to inhibit or slow down the growth and proliferation of cells, a particularly significant aspect in cancer studies where uncontrolled cell division is a hallmark of the disease. Substances displaying antiproliferative properties are of great interest due to their ability to disrupt the cell cycle, induce apoptosis, or target specific signaling pathways, thereby hindering the unchecked growth of cancer cells. Compounds derived from secondary metabolites, such as polyphenols, flavonoids, alkaloids, and terpenoids, have been identified for their potential antiproliferative effects (Sheikh *et al.*, 2020). Berberine, for instance, has been found to inhibit the growth of liver cancer cells by impeding glutamine uptake (Zhang *et al.*, 2019). Additionally, Chen et al. (2019) reported that α-humulene (sesquiterpene) inhibits the Akt signaling pathways, consequently inducing apoptosis in hepatocellular carcinoma cells.

As young and rapidly growing plants, microgreens have garnered attention for their potential antiproliferative activity. These tiny plants are rich sources of secondary metabolites, particularly polyphenols and flavonoids, associated with anticancer properties. Studies suggest microgreens may exert antiproliferative effects by influencing cancer cell signaling pathways. For example, the aqueous extracts of the green pea, soybean, radish, Red Rambo radish, and rocket microgreens exert an antiproliferative effect against the sarcoma cells (Truzzi *et al.*, 2021). Moreover, Fuente et al., (2020) revealed that four Brassicaceae microgreens, namely broccoli, kale, mustard, and radish, possess antiproliferative effects against the human colon cancer cells. The unique combination and concentration of bioactive compounds in microgreens make them promising candidates for dietary interventions to prevent or complement conventional cancer treatments. Thus, exploring microgreens in cancer studies holds the potential to discover natural sources of antiproliferative agents, contributing to developing preventive and therapeutic strategies against cancer.

### 3.7.2. Health Challenges of Microgreens

The health challenges associated with microgreen cultivation, specifically bacterial contamination, pesticide residues, and nutritional imbalances, underscore critical considerations in ensuring the well-being of consumers. Bacterial contamination poses a direct risk to human health, as certain pathogens can thrive in the warm and humid conditions ideal for microgreen growth, potentially leading to foodborne illnesses. In this case, the warm and humid conditions conducive to microgreen growth increase the risk of bacterial contamination and create an environment favorable for other issues, such as *Pythium* and *Phytophthora* infections (Nolan, 2019). Given the susceptibility of microgreens to *Pythium* and *Phytophthora* in warm and humid conditions, it becomes crucial to control the cultivation environment. This includes maintaining optimal temperature and humidity levels to discourage the growth of these pathogens.

Furthermore, pathogen-infected seeds stand out as a significant health challenge in microgreen cultivation (Ali *et al*., 2022). Pathogens such as bacteria or fungi can reside within seeds, posing a direct risk to the health of the emerging seedlings. As microgreens are typically consumed at an early stage of growth, the contamination of seeds can lead to the propagation of harmful microorganisms, potentially resulting in foodborne illnesses for consumers. Stringent quality control measures in seed sourcing, testing, and sanitation practices are crucial to address this challenge (Vishunavat *et al.*, 2023). Ensuring that seeds are free from pathogens before germination is essential in maintaining the safety and integrity of microgreens, emphasizing the need for preventive measures at the beginning of the cultivation process to safeguard consumers' health.

Lastly, irrigation with contaminated water poses a significant health challenge in the cultivation of microgreens. As these young seedlings absorb water directly through their delicate tissues, using contaminated irrigation water can introduce harmful pathogens (Chen *et al*., 2023). This can result in a heightened risk of bacterial contamination and harmful substances in the microgreens. Consumers may unknowingly be exposed to these contaminants upon consumption, potentially leading to adverse health effects. Mitigating this challenge requires rigorous water quality management, including regular testing, proper filtration systems, and adherence to strict hygiene protocols during irrigation (Alegbeleye & Sant'Ana, 2022). Safeguarding the water sources used in microgreen cultivation is essential to ensure the production of safe and healthy microgreens for consumption, underscoring the significant role of water safety in addressing health concerns associated with microgreen cultivation.

## 4. Conclusion and Recommendations

Microgreens have evolved beyond their initial role as nutritional powerhouses, becoming versatile, functional foods with numerous benefits. Cultivating microgreens enhances ecosystems and provides vital nutrients for our well-being. Urban agriculture projects in cities like San Francisco, Seoul, Tokyo, Jakarta, and Singapore have demonstrated the practicality of growing microgreens locally, reducing the need for extensive land and equipment. Adding microgreens to our daily diets boosts nutrition and food security, particularly for small businesses in low-income areas. Their minimal use of chemicals and reduced transportation requirements highlight their eco-friendliness. Research has revealed that microgreens contain superior nutrients and phytochemicals, including essential polyphenols like kaempferol, quercetin, and resveratrol, which exhibit valuable health-promoting properties. Recent studies have unveiled various biological activities, from antioxidant to antimicrobial effects, highlighting their potential for improving health. Future research should delve into unexplored compounds within microgreens, solidifying their status as essential dietary components for healthier lives. Clinical studies are necessary to assess the long-term effects of microgreens consumption in preventing diet-related diseases.

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### Credit Authorship Contribution Statement

**Muhammad Amirul Amil**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Hazwani Mat Saad**: Formal analysis, Methodology, Writing – review & editing, Data curation. **Chun Hoe Tan**: Formal analysis, Methodology, Writing – review & editing, Data curation. **Kae Shin Sim**: Conceptualization, Formal analysis, Writing – review & editing, Funding acquisition, Resources, Supervision.

### Declaration of Competing Interest

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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