Microgreens – a multi-mineral and nutrient rich food

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Introduction

Mineral malnutrition (e.g., Fe and Zn) is one of the most important global challenges affecting two-thirds of the world's population (Weber, 2017) from every economic status, and the problem is intensified by current agricultural practices. The lack of soil, space, outdoor garden sites, and time to commit to traditional vegetable cultivation, as well as the high cost of production, are some of the challenges that need innovative approaches. Current efforts to mitigate mineral malnourishment have focused on developing bio-fortification methods (White et al., 2009), genetic engineering and manipulation of the crops to maximize nutrient uptake (Grusack, 2002). Yet, other strategies exist to solve these problems. For instance, microgreens, a new category of salad crops gaining popularity and interest over the past few years, represent a rich source of nutrients and vitamins with nutraceutical properties (Mir et al., 2017). They do not rely on bio-fortification or genetic engineering/manipulation. They can play an important role in human health. This may explain their recent popularity and increased consumption. Moreover, these young seedlings contain lower nitrate concentrations compared with baby leaf or adult plants of the same species (Bulgari et al., 2017). Xiao et al. (2012) found that microgreens contain much higher concentrations of vitamins and carotenoids than the respective adult species. Similarly, Sun et al. (2013) reported that microgreens of five *Brassica* species displayed more complex polyphenol profiles compared with their mature counterparts. Microgreens are seedlings and edible cotyledons of many vegetables, herbs and flowers used to provide a range of colors, textures and flavors to a wide variety of dishes (Xiao et al., 2012; Pinto et al., 2015; Mir et al., 2017). They represent a new culinary trend; they are particularly popular with gourmet chefs around the world. However, most people who cook their own food find microgreens too expensive to purchase. Growing of microgreens in residential gardens can however be an affordable alternative.

What are microgreens and how are they used?

Microgreens are a new class of edible greens of vegetables, herbs (basil, cilantro), and flowers that are young and tender, having two fully developed cotyledon leaves with or without the emerging first true leaves. According to Kou et al. (2013), they are harvested at the first true leaf stage, just above the roots, and consumed fresh as salad greens. These are typically a special category of greens by their size and age (Pinto et al., 2015) among the wide variety of greens available in the market. They are larger than sprouts but smaller than baby versions of popular vegetables such as lettuce, spinach, baby salad leaf and baby corn. Microgreens can be eaten raw at the seed leaf (cotyledon) stage, except the root, or often, one to two true leaves are allowed to form and provide more plant weight. Microgreens are 2.5-10 cm in height depending on the species and can provide a wide array of intense flavors, colors and textures (Xiao et al., 2012). Production can vary by species, but often microgreens can be harvested within 7-14 days after sowing under optimum growing conditions (Lee et al., 2004; Xiao et al., 2012, 2014a). The seeds are sown at a high density to maximize yields. Arugula (rocket), spinach, radish, celery, cilantro, purple mustard, chard, red beet, green pea and pepper cress are examples of typical microgreens. Some of these, like arugula, fennel, cilantro and basil, have distinct flavors that intensify the taste profile of the dominant greens in a salad or other dishes.

Microgreens versus sprouts

Microgreens are different from sprouts and are harvested before they develop into larger plants and are grown in a shallow container of soil. The unique differences between

Table 1. Differences between microgreens and sprouts.

Microgreens	Sprouts
Microgreens are defined as leafy vegetables and herbs shoots used to enhance salads or as edible garnishes to embellish a wide variety of other dishes (Mir et al., 2017)	Sprout seeds are usually nuts, grains or beans and are consumed after germination or partially after germination
Microgreens are harvested just above the roots; the stem, cotyledons and first true leaves are eaten	Sprouts are eaten with their roots intact. Hence these seeds are washed properly to remove foreign substances and soil particles
Microgreens are grown over soil surface or other growing medium such as peat moss, vermiculite and perlite (Murphy et al., 2010; Xiao et al., 2014b)	Sprouts are grown entirely in water in an enclosed container such as a glass jar. The seeds are soaked in water in various time-temperature schedules depending on the type and size of seeds (Bergquist et al., 2006; Xiao et al., 2014a)
Seed density is low as the young greens need space to grow	Seed density is high
Microgreens take more time to grow than sprouts as leaves are larger and greener (Poorva and Aggarwal, 2013)	It takes relatively less time to grow than microgreens
These greens require sunlight for their efficient growth	Sprouts are grown in high moisture, humidity levels, optimum temperature and dark or low-light conditions
Microgreens present relatively less risk of food borne illness than sprouts	Sprouts have a high risk of food borne illnesses because their growing conditions are also ideal for the growth of bacteria

Figure 1. Red cabbage microgreens at cotyledon stage after 16 days.

Figure 2. Harvested white cabbage microgreens.

microgreens and sprouts enumerated by different authors are listed in Table 1.

Benefits of microgreens

Microgreens are a much richer source of functional components such as antioxidants, phenolics, vitamins and minerals than their respective mature greens or seeds (Xiao et al., 2012; Janovska et al., 2010). Besides normal nutritional values, they have health promoting or disease preventing properties, and are thus highly prized and considered as "functional foods". Microgreens add unique textures, and unusual flavors to meals (Xiao et al., 2012; Pinto et al., 2015; Mir et al., 2017). Microgreens get their color from naturally occurring pigments found in plants. Microgreens are a rich source of antioxidants and other phytonutrients potentially beneficial to human health and have been shown to lower the risk of certain cancers and heart diseases (Xiao et al., 2012). The most common phytonutrients found in microgreens are β-carotene and other carotenoids and vitamins K, C and E. These tiny plants can be used to brighten up a wide variety of main dishes with their vivid color ranges (Treadwell et al., 2010; Wallin, 2013). Microgreens are added to various dishes whole or chopped. Coarsely chopping herb microgreens help to bring out their unique flavors and aroma. Microgreens should not be heated since they quickly deteriorate when cooked, although they can be added as garnish on top of hot dips or dishes. They can be used generously in cold dishes like salads, smoothies and sandwiches (Kou et al., 2014).

Microgreens production and utilization

Microgreens can be grown commercially and at a smaller scale by individuals for home use, either as sole crop or mixed crop (Poorva and Aggarwal, 2013). Identifying the right stage of harvest is one of the most important production practices to obtain an appropriate mix of microgreens. The time required for germination to attain a harvestable stage greatly varies from crop to crop (Allende et al., 2004; Pinto et al., 2015). For mixed cropping, the growers have to select the crops with similar growth rates, so that the entire crop can be harvested at once. Sometimes the growers raise various crops as monocultures and then mix them after harvest (Mir et al., 2017). Commonly cultivated microgreens are spinach (Lester and Hallman, 2010), table beet (Murphy et al., 2010; Pill et al., 2011), mustard (Kopsell et al., 2012), buckwheat (Kou et al., 2013), arugula, celery, red cabbage (Figure 1), white cabbage (Figure 2), broccoli, radish and lettuce (Xiao et al., 2012; Chandra et al., 2012; Sun et al., 2013; Kou et al., 2014; Xiao et al., 2014a, b; Pinto et al., 2015).

Microgreens production at home

Microgreens may be produced in home gardens or backyards under optimum growing conditions. They can also be grown in greenhouses or indoor in urban situations, if the temperature ranges from about 18-25°C and light levels and day lengths are sufficient. Such small-scale home production could be encouraged in nutrient-deficient populations (e.g. in keyhole gardens that are being encouraged in Africa (www.sendacow.org).

Growing media and production sites

Since microgreens are fragile and sensitive to physical damage, they should be protected from rainfall and other environmental stresses. They can be grown in greenhouses, high tunnels, shade structures or indoors. Microgreens have a short growing cycle and are mainly produced hydroponically or

Table 2. Common vegetable and herb species suitable for microgreens production and suitable seasons/growing conditions (Bumgarner and Metallo, 2018).

Cool-season vegetables	Warm-season vegetables	Herbs grown as microgreens
Kale, broccoli, cabbage, beets, Swiss chard, pea, lettuce, mizuna, arugula, pak choy, turnip, radish, endive, mustard, cress, carrot	Amaranth, sweet corn	Basil, cilantro, parsley, fennel, dill, marjoram
Growing conditions		
Requires temperatures around 21-23°C and slightly lower temperatures and light conditions	Requires temperatures around 24-27°C and bright sunshine	

semi-hydroponically. Under hydroponic systems, microgreens can be produced using perlite or vermiculite. Sterilized growing media should be used to avoid the risk of pest and disease development. Depending on the requirements they are also produced in garden beds, in window sills as well as in containers (Mir et al., 2017). Microgreens may also be produced in flat nursery beds or plug trays with soil or compost mixed with vermicompost under conventional systems. They may be produced in plastic trays with bottom holes to allow drainage. According to Kou et al. (2013) they can be grown in a standard, sterile, loose soil and many mixes have been used successfully with peat, vermiculite, perlite and bark.

Growing conditions

Different vegetables and herbs used for microgreens have different growing requirements (Table 2). Cool-season crops, such as broccoli, lettuce (Figure 3) and arugula, will germinate well in temperatures of around 21-23°C, but can also grow at slightly lower temperatures. The growth rate of cruciferous vegetables, such as broccoli, arugula, radish and pak choy, will be higher at moderate light and temperature conditions. Quick germination and higher germination percentages were noticed when warm season crops, such as amaranth (Figure 4) and basil (Figure 5), were sown at temperatures from 24-27°C. Cool-season crops, such as lettuce and arugula, may grow well under slightly lower light conditions, compared with herbs like basil and some other warm-season crops.

Seeds and sowing

The vegetable and herb seeds used for microgreens production should not be treated with any plant protection chemicals (Weber, 2017). Seeds are sown either in rows or are broadcasted. To maximize production, dense sowing is advised but sowing seeds too densely provides an ideal environment for pests (e.g. aphids and thrips) and diseases, particularly *Pythium*, *Phytophthora* and damping-off. However, *Sclerotinia* and *Rhizoctonia* diseases may also pose a problem to some hosts (Kaiser and Matt, 2012). Moreover, overcrowding encourages elongated stems (Mir et al., 2017). To avoid the pest and disease load, and also to reduce excessive stem elongation, the seeds should be sown at optimum spacing. The seeds of larger-seeded crops, such as pea (Figure 6), beet and chards, are soaked in water prior to sowing, to speed up the germination. These seeds are covered with 0.5-0.6 cm of growing media to prevent drying during germination. From a grower's point of view, total shoot fresh weight (FW) is often the preferred yield determinant to achieve high return. Uniformity and speed of crop establishment indirectly increases the total fresh weight of the crop. Lee et al. (2004) examined several seed treatments to advance greenhouse establishment of table beet and chard microgreens. The most pronounced seedling emergence advancement was gained by germinating seed balls in fine-grade exfoliated vermiculite (150% water [weight per vermiculite dry weight (DW)] for 3 days at 27°C) and sowing the germinated seed ball vermiculite mixture. Similarly, Murphy and Pill (2010) and Murphy et al. (2010) found that pre-sowing germination (pregermination) of arugula/rocket seeds (*Eruca vesicaria* subsp. *sativa*) in fine-grade exfoliated vermiculite, moistened with 200% water (weight per vermiculite DW) for 1 day at 20°C, produced the greatest shoot FW m^{-2} 15 days after planting (10.14 kg m^{-2}).

Watering

After germination, the seedlings should be watered using a watering can or micro sprinklers. Bottom watering is best because it keeps stems and leaves dry and reduces disease risk. However, the growing media should be kept moist, but not saturated. Overwatering can lead to stunted or deformed growth and there is a risk of pest and disease development. Flooding encourages fungal disease incidence in foliage. During the summer months, the growing area may be covered with a shade net or microgreens containers may be moved to shady areas to avoid photo-bleaching.

Nutrient supplements

Since microgreens are harvested at an immature stage and consumed as such, fertilizers are not usually necessary because the seeds have sufficient nutrition for the young crop (Xiao et al., 2015). Organic supplements such as compost, vermicompost mixed with growing media mostly increase the yield of microgreens (Murphy et al., 2010). In addition, water soluble organic nutrients derived from compost teas may be used to enhance the growth of microgreen seedlings. However,

Figure 3. Speckled loose-leaf lettuce microgreens.

Figure 4. Amaranth microgreens.

Figure 5. Basil microgreens at true leaf stage.

soilless media may be supplied with small amounts of water soluble fertilizers. This can be particularly useful for speeding up the growth of slow growing microgreens, such as parsley and basil.

Pest and diseases

There are few pest and disease problems associated with microgreens because the growth cycle is short, and soilless mixes and paper pads are essentially free of pathogens. Microgreens that are too densely planted can have issues of poor air flow and water saturation in the root zone. Moreover, over-seeding, overwatering, poor airflow, low light levels and extreme temperatures can cause poor germination or seedling death. Algal growth around the young plants can become a problem in production of microgreens, which hampers the growth of seedlings, but it poses little threat to plants. Low light levels and overcrowding can also cause yellowing of leaves, and stretching and thinning of stems. Continuous exposure to high temperatures will cause leaf curling, stunting, yellowing of leaves and seedling death. Potential pests that can affect microgreens' production include thrips, whitefly, and aphid. Dense sowing of seeds provides an ideal environment for these pests and for damping-off diseases, particularly *Pythium* and *Phytophthora*. However, *Sclerotinia* and *Rhizoctonia* diseases may also pose a problem to some hosts (Kaiser and Matt, 2012). Many of these diseases can be prevented through sparse sowing, good sanitation practices, adequate air circulation and proper water management.

Harvesting and storage

Microgreens are commonly harvested at one time for convenience, using clean scissors or small hand pruners. The harvested fresh microgreens should be marketed and consumed as rapidly as possible, and home-grown microgreens should only be harvested immediately prior to consumption. Cutting height is important to ensure that growing media particles do not contaminate the product. Microgreens are harvested when the first set of cotyledon leaves and true leaves have developed, usually at about 5 cm tall, but it is dependent on the type of crop (Mir et al., 2017). The time from germination to attain a harvestable stage greatly varies from 1-3 weeks depending on the crop (Allende et al., 2004; Xiao et al., 2014a). The approximate time required for different species to attain a harvestable stage, and the most suitable storage temperatures, are listed in Table 3. Microgreens are delicate seedlings that should be handled with care when harvested. After harvesting, they should be thoroughly washed with clean water to remove any residual soilless mix and plant debris. Mir et al. (2017) stated that harvested microgreens are highly perishable and need to be washed and cooled as quickly as possible using good handling practices for food safety. They should then be patted dried gently or rolled with paper towels to remove excess water before placing in containers for storage. Microgreens should be placed in rigid plastic containers to protect against crushing and to prolong the shelf life of the packaged product. According to Kou et al. (2014) and Xiao et al. (2014b) microgreens are usually packed in polyethylene packages and cooled to recommended temperatures before supplying to the market or consumers. Since microgreens are harvested at the cotyledon stage, the immature tissue structure of microgreens has a very short shelf life at ambient temperature and various techniques are used to enhance the shelf life of the pro-

Table 3. Commonly grown microgreens: time required to attain harvestable stage and storage conditions.

Crop	Harvestable stage	Storage	References
Spinach	10 days	Polyethylene film at 5°C	Allende et al., 2004
		Oriented polypropylene at 2 or 10°C for 5 or 9 days	Bergquist et al., 2006
Table beet	15 days		Murphy et al., 2010
Buckwheat	5 cm height	Polyethylene films, stored at 1, 5, 10, 15 or 20°C for 14 days and at 5°C for 21 days	Kou et al., 2013
Broccoli	9 days	Polyethylene film at 5°C	Kou et al., 2013
Radish	7 days	Polyethylene film at 1°C	Xiao et al., 2014a
Lettuce	14 days	Freeze dried	Pinto et al., 2015

Figure 6. Pea microgreens ready for harvest.

duce. The two important techniques used for increasing the postharvest shelf life are storage temperature and storage atmospheric conditions. Microgreens can be stored in the refrigerator (4°C) from a few days to two weeks depending on the species.

Conclusion

In the last few years, microgreens have gained popularity because of changes in life style patterns and health consciousness of consumers. Due to their high concentration of antioxidants, vitamins and minerals, and low nitrate content, which are linked with the promotion of good human health, microgreens have great potential to be a positive and simple way to reduce the number of people suffering from mineral malnutrition.

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