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Review

Micro-scale vegetable production and the rise of microgreens

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ABSTRACT

Background: Interest in fresh, functional foods is on the rise, compelled by the growing interest of consumers for diets that support health and longevity. Microgreens garner immense potential for adapting leafy vegetable production to a micro-scale and for improving nutritional value in human diet.
Scope and approach: Major preharvest factors of microgreens production, such as species selection, fertilization, biofortification, lighting and growth stage at harvest are addressed with respect to crop physiology and quality, as well as postharvest handling and applications, temperature, atmospheric composition, lighting and packaging technology which influence shelf-life and microbial safety. Key prospects for future research aiming to enhance quality and shelf-life of microgreens are highlighted.
Key findings and conclusions: Effective non-chemical treatments for seed surface sterilization and anti-microbial action, pre-sowing treatments to standardize and shorten the production cycle and crop-specific information on the interaction of sowing rate with yield and quality deserve further attention. Indigenous landraces, underutilized crops and wild edible plants constitute a vast repository for selection of genetic material for microgreens. Modular fertilization may fortify microgreens bioactive content and augment their sensorial attributes. Pre- and postharvest select-waveband, intensity and photoperiod combinations can elicit compound-specific improvements in functional quality and in shelf-life. Research is needed to identify effective sanitizers and drying methods non-abusive on quality and shelf-life for commercialization of ready-to-eat packaged microgreens. Genotypic variability in postharvest chilling sensitivity and the interactions of temperature, light conditions and packaging gas permeability should be further examined to establish environments suppressive on respiration but preventive of off-odor development.

1. The state of micro-scale vegetable production: sprouts, baby greens, microgreens

Over the past twenty years, interest in fresh, functional and nutraceutical foods has been on the rise, compelled by the growing interest of society in healthy eating (Ebert, 2012). Consumers are questing for new products that support health and longevity combined with gastronomic delight (Drewnowski & Gomez-Carneros, 2000). Accordingly, it is in the best interest of specialty crop growers, extension specialists and researchers to tap upcoming trends and opportunities for niche products. Microgreens, frequently called ‘vegetable confetti’, are a new class of speciality crop, defined as tender immature greens produced from the seeds of vegetables, herbs, or grains, including wild species (Xiao, Lester, Luo & Wang, 2012). Depending on species and growing conditions, microgreens are generally harvested at the soil level, i.e. at the base of hypocotyls, upon appearance of the first pair of true leaves, when cotyledons are fully expanded and still turgid, usually within 7–21 days from seed germination depending on the species (Fig. 1) (Sun et al., 2013). The idea of microgreens originated in the late 80's in San Francisco, California, and they have since gained popularity as hot novel culinary ingredients in the world's finest restaurants and upscale grocery stores (Treadwell, Hochmuth, Landrum & Laughlin, 2010). Their popularity stems

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Fig. 1. Ready to harvest microgreens of (**A**) red beet (*Beta vulgaris* L.), (**B**) cilantro (*Coriandrum sativum* L.), (**C**) radish (*Raphanus sativus* L.), and (**D**) brassica raab (*Brassica rapa* L., Broccoletto group), grown in trays on a peat mix (A, B and C), or in hydroponic growing channels on a fibrous mat (D). Photos courtesy of Francesco Di Gioia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

from their vivid colors, delicate textures, unique flavor enhancing properties as garnishes (e.g. in salads, sandwiches, soups entrées, desserts and drinks), but also from their fortified phytonutrient content and potential bioactive value (Sun et al., 2013; Xiao, Lester, et al., 2015, Xiao et al., 2012). Supply and demand of microgreens is highly influenced by emerging gastronomic trends, and species selection relies on producer interaction with chefs and on consumer familiarization with their particular sensory attributes (Koppertcress, 2016). Microgreens may be distributed as fresh-cut products but also while growing on media, to be harvested by end users. Mostly exploited are species belonging to the families *Brassicaceae*, *Asteraceae*, *Chenopodiaceae*, *Lamiaceae*, *Apiaceae*, *Amarillydaceae*, *Amaranthceae* and *Cucurbitaceae*. Bioactive content is prominent in species of rather acrid taste (e.g. *Brassicaceae*), the variable acceptability of which warrants identification of genotypes that may cater to demands for both taste and health (Xiao, Lester, et al., 2015).

Microgreens are distinct from sprouts even if both *greens* are consumed in an immature state (Treadwell et al., 2010). Sprouts are generally grown in dark, moisture saturated conditions conducive to microbial proliferation, and their consumption, unlike that of micro- and baby-greens, has been implicated in outbreaks of foodborne epidemics (Ebert, 2012; Xiao, Nou, Luo, & Wang, 2014). Also, microgreens have much stronger flavor enhancing properties than sprouts, and a broad range of leaf color, variety and shape (Ebert, 2012). Recent reports demonstrated that microgreens contain higher amounts of phytonutrients (ascorbic acid, β-carotene, α-tocopherol and phylloquinone) and minerals (Ca, Mg, Fe, Mn, Zn, Se and Mo) and lower nitrate content than their mature-leaf counterparts (Table 1) (Pinto, Almeida, Aguiar, & Ferreira, 2015; Xiao et al., 2012). The appeal of microgreens to consumers, coupled to their high price market and short production cycle, has attracted greenhouse growers and many urban and peri-urban farms have invested in their production. On the other hand, microgreens low yield, rapid senescence and very short shelf-life curbs the expansion of their commercial production (Chandra, Kim, & Kim, 2012; Kou et al., 2013).

As a novel crop, microgreens are still in relative infancy, with yet limited available scientific information but expanding research generating insight into their immense potential as *superfood*. The present review focuses on recent advances on microgreens, particularly on the impact of preharvest factors (species selection, fertilization, biofortification, lighting and harvest stage) on their physiology and quality, as well as of postharvest factors (handling and applications, temperature, atmospheric composition, lighting and packaging technology) on their quality, postharvest performance and microbial safety. The review concludes by identifying major prospects for future research aiming to enhance production efficiency, product quality and shelf-life of microgreens.

2. Growing microgreens: seeds, growing media, harvesting

Seeds are demanded in large quantity and represent a major cost for the production of quality microgreens (Di Gioia, Mininni, & Santamaria, 2015). Unlike sprouts, foodborne outbreaks have not been associated so far with the consumption of microgreens; however, the systemic risk posed by contaminated seeds raises requirements for seed microbiological quality (Xiao, Bauchan et al., 2015; Xiao et al., 2014). Seeds should receive precautionary sanitary treatments for eliminating pathogenic bacteria such as those recommended for sprouts production by the U.S. Food and Drug Administration. Effective and sustainable, non-chemical treatments need to be identified for seed surface sterilization and antimicrobial action appropriate for production of organic microgreens (Ding, Fu, & Smith, 2013). Preliminary germination test per seed lot is advisable for adjusting sowing rate (Di Gioia et al., 2015). Many species germinate easily and grow promptly while others are slow and may require pre-sowing treatments to improve, standardize and shorten the production cycle (Lee, Pill, Cobb, & Olszewski, 2004). Treatments used to advance the early stages of germination range from simple water soaking to physiological treatments, such as osmopriming, matrix priming and seed pre-germination (Table 2). Optimal sowing rate is crop-specific, based on average seed weight, germinability and desired shoot population density,