agronomy

Editorial

Sprouts, Microgreens and Edible Flowers as Novel Functional Foods

Youssef Rouphael [1,*], Giuseppe Colla [2] and Stefania De Pascale [1]

[1] Department of Agricultural Sciences, University of Naples Federico II, 80055 Portici, Italy; depascal@unina.it
[2] Department of Agriculture and Forest Sciences, University of Tuscia, 01100 Viterbo, Italy; giucolla@unitus.it
* Correspondence: youssef.rouphael@unina.it; Tel.: +39-081-253-9134

check for updates

Citation: Rouphael, Y.; Colla, G.; De Pascale, S. Sprouts, Microgreens and Edible Flowers as Novel Functional Foods. *Agronomy* **2021**, *11*, 2568. https://doi.org/10.3390/agronomy11122568

Received: 5 December 2021
Accepted: 15 December 2021
Published: 17 December 2021

Nowadays, interest in novel functional foods has been on the rise, compelled by the increased interest of the consumers, researchers, food nutritionists, producers, and extension specialists for diets able to maintain health and preventing chronic diseases by providing essential nutrients, phytochemicals, and calories for the body metabolism. Sprouts, microgreens, and edible flowers are three important classes of specialty crops produced from the seeds of a wide range of ornamental plants, fruit trees, vegetables, herbs, cereals as well as wild species. Sprouts, microgreens, and edible flowers are normally consumed raw, and they are characterized by their phytochemical profile particularly, phenolic compounds (phenolic acids, anthocyanin, chalcone, flavanones, flavones, flavonols), carotenoids (carotenes and xanthophylls), betalains (betacyanins and betaxhantins), vitamins (ascorbic acid, phylloquinone, and tocopherols), glucosinolates, amino acids as well as macro and micro-minerals [1–3].

The current special issue "Sprouts, Microgreens and Edible Flowers as Novel Functional Foods" compiles one critical review and nine original research articles that examine the implications of preharvest and postharvest factors on agronomical performance, nutritional and functional quality of sprouts and microgreens. The present special issue contains scientific papers of high-quality standard coming from several prestigious and renown research groups. As such, it is geared to improve knowledge among consumers, academics, breeding companies and farming communities on the benefits of these three important categories of specialty crops towards providing and designing fresh, healthier (low calorific and fat content) and functional (phytochemicals-rich) foods [1–3].

Sprouts which are basically germinated seeds of cereals, pseudo-cereals, legumes, herbs, oilseeds, and vegetables usually grown under dark conditions without the use of a substrate and the addition of synthetic agrochemicals and fertilizers since only water is required. They are characterized by a very short cultivation cycle (4 to 10 days) and their edible portion is constituted by the whole sprout including the roots [4]. The nutritional and functional quality of sprouts, microgreens and edible flowers are modulated by several preharvest (species/genotypes choice, mineral nutrition, micro-elements biofortification, light intensity and spectrum composition). Cuong et al. [5] carried out an experiment aiming to determine the effects of increasing concentrations of sodium chloride (0, 50, 100 or 200 mM NaCl) on phenylpropanoid compounds and their related genes. Increasing the NaCl concentration from 0 to 200 mM decreased linearly the agronomical traits such as fresh weight, shoot and root lengths. Interestingly, the highest concentrations of epicatechin, ferulic acid trans-cinnamic acid, 4-hydroxybenzoic acid, and total phenylpropanoid were recorded on 6-day-old wheat sprouts treated with 50 mM NaCl. The authors concluded that the application of moderate saline stress (50 mM NaCl) could be considered an effective agronomical tool to improve the synthesis and accumulation of phenylpropanoid compounds in wheat sprouts with a marginal decrease in fresh biomass. Moreover, Martínez-Zamora et al. [6], carried out an experiment to assess the beneficial effect of light-emitting diode (LED) stimuli in the phytochemical synthesis and accumulation of carrot sprout. In their growth chamber trial, carrot seeds were grown under darkness conditions for 7-days and after this initial period sprouts were subjected to different daily light treatments (darkness, fluorescent, blue + red, blue + red + far red) with the following photoperiod regime: 16 h light and 8 h of darkness. Although sprout and hypocotyl lengths were improved under control conditions (i.e., darkness), LED stimuli with blue + red and with blue + red + far red increased both phenolic compounds (chlorogenic, caffeic acid, rutin), and carotenoids compared to fluorescent and especially the control treatment. The authors concluded that the application of LED lighting during sprouting could boost the synthesis and accumulation of key pigments in carrot such as carotenoids. Similar findings were also observed in ginseng spouts cultivated under 16 light treatments including: natural white, fluorescent, monochromatic (blue, red, or green), various red-blue, red-green-blue combinations as well as supplemental far red [7]. Particularly, red light significantly increases growth characteristics (shoot, and total fresh weight, leaf area, and stem length) as well as photosynthesis parameters (SPAD value, photosynthetic rate, and stomatal conductance), while the highest total saponin and ginsenosides contents was recorded in ginseng sprouts treated with the combination of natural white + far red.

In addition to sprouts, microgreens also known as 'vegetable confetti' are another important class of specialty crop, defined as tender immature greens produced under light conditions from the seeds of vegetables, herbs or grains, including wild species. The most popular microgreens are produced from seeds of the following plant families: Asteraceae, Apiaceae, Amaryllidaceae, Amaranthaceae, Lamiaceae and Brassicaceae [8–11]. Microgreens are generally harvested at the soil level, 7 to 28 days from seed germination (depending on the species/varieties and cultivation conditions). The edible portion of microgreens is constituted of the two cotyledons and the first and/or second true leaves without roots.

Concerning the implications of mineral nutrition on the productive characteristics and bioactive profile of microgreens El Nakhel et al. [12] and Keutgen et al. [13] shed light on the importance of this preharvest factor (i.e., mineral nutrition) on novel microgreens species from the Brassicaceae botanical family. El Nakhel et al. [12] demonstrated that growing microgreens species such as Brussels sprouts and cabbage without fertilization application (only osmotic water was used during the whole cultivation cycle) can be feasible (10% of yield reduction accompanied with an 99% reduction of nitrate compared to nutrient supplementation treatment). In the same study, the absence of nutrient supplementation in microgreens rocket exhibited a significant increase in a wide range of metabolites such as β-carotene, lutein, and ascorbic acid but manifested a major 47% decrease in fresh yield. Moreover, Keutgen et al. [13] examine the effect of five nutrient solution concentrations (full-, half- and quarter-strength NSs, tap water and demineralized water) on nutritional and sensorial quality of garden cress and radish cress. The authors demonstrated that the induction of moderate nutrient stress may represent an efficient tool to modulate the bioactive compounds, whereas the sensory attributes of the two tested microgreens was rated highest when macronutrient content in the nutrient solution was highest. The consumer acceptability and sensory attributes of 12 microgreens species/genotypes (komatsuna, tatsoi, pak choi, cress; mibbuna, mizuna, Swiss chard, amaranth, coriander, green basil, purple basil, purslane was assessed by Caracciolo et al. [14], on a sample of 54 untrained student's volunteers having an average age of 22 years. The authors demonstrated that the lower the sensory attributes such as astringency, bitterness, and sourness the higher the consumer acceptability of microgreens species. Particularly, mibuna and cress (Brassicaceae) exhibited the lower acceptance of by consumers, whereas Swiss chard (Chenopodiaceae) and coriander (*Apiaceae*) where the most requested and appreciated by the consumers.

Human body deficiency in essential and/or beneficial microelements has become a serious threat among the global population. Biofortification of vegetables crops and microgreens with key microelements such as iodine, iron, selenium, and zinc may represent an effective approach for providing the human diets with these important beneficial and essential microelements [15,16]. Puccinelli et al. [17] investigated how the application of 1.5 mg/L of sodium selenate could biofortified three wild species *Rumex acetosa* L., *Plantago coronopus* L., and *Portulaca oleracea* L., grown as microgreens. All microgreens' species exhibited an increase in the selenium concentration in the shoot parts in particular *P. coronopus* which was characterized by the highest ability to accumulate selenium, and the selenium enriched microgreens showed the highest flavonoid and chlorophyll content. The authors concluded that a daily consumption of 10 g of wild species microgreens fortified with 1.5 mg/L of Se will satisfied 27–53% of the recommended daily allowance for selenium.

The increasing consumption of microgreens as nutrient dense vegetables invites a closer examination of their comparative composition compared to their mature greens' counterparts [18]. In this special issue two research articles have addressed the differences in nutritional and functional quality between microgreens and mature plants [19,20]. Di Bella and co-workers [19] investigated the variation of secondary metabolites and functional quality of two broccoli types ('Broccolo nero' and 'Cavolo broccolo Ramoso Calabrese') and kale ('Cavolo Lacinato Nero di Toscana') at three different growth stages: sprouts, microgreens, or baby leaf. The highest concentration of kaempferol and apigenin was observed at the baby leaves growth stage, whereas the highest value of ascorbic acid was observed for the microgreens of 'Broccolo Nero'. Moreover, the antioxidant capacity showed in general the highest values for the sprouts for all the two broccoli and kale analyzed. In a similar growth chamber experiment, El-Nakhel et al. [20] examined the antioxidant molecules and mineral profile of parsley at two different stages of ontogeny (microgreens and baby leaves). The authors showed that microgreens provided more key carotenoids (lutein and β-carotene), more potassium and phosphorus and less nitrate, whereas parsley baby leaves provided more total polyphenols and total ascorbic acid. The authors concluded that both ontogeny maturity stages of parsley presently examined have proven potential sources of phytochemicals for the human diet. Finally, concerning the future perspectives in the field of specialty crops, Galieni et al. [21] reviewed the potential benefits of sprouts and microgreens as functional foods. In their review paper, they indicated that future efforts should focus on new research prospects related to key preharvest (seeds treatments, biofortification and elicitation techniques) as well as to postharvest techniques (shelf-life extension and seed sanitation) that may additionally enhance target phytochemicals in these important specialty crops.

Author Contributions: Conceptualization, Y.R.; writing—original draft preparation, Y.R.; writing—review and editing, Y.R., G.C. and S.D.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kyriacou, M.C.; Rouphael, Y.; Di Gioia, F.; Kyratzis, A.; Serio, F.; Renna, M.; De Pascale, S. Micro-scale vegetable production and the rise of microgreens. *Trends Food Sci. Technol.* **2016**, *57*, 103–115. [CrossRef]
2. Aloo, S.O.; Ofosu, F.K.; Kilonzi, S.M.; Shabbir, U.; Oh, D.H. Edible Plant Sprouts: Health Benefits, Trends, and Opportunities for Novel Exploration. *Nutrients* **2021**, *13*, 2882. [CrossRef]
3. Pires, D.O.E., Jr.; Di Gioia, F.; Rouphael, Y.; Ferreira, I.C.F.R.; Caleja, C.; Barros, L.; Petropoulos, S.A. The Compositional Aspects of Edible Flowers as an Emerging Horticultural Product. *Molecules* **2021**, *26*, 6940. [CrossRef]
4. Di Gioia, F.; Renna, M.; Santamaria, P. Sprouts, Microgreens and "Baby Leaf" Vegetables. In *Minimally Processed Refrigerated Fruits and Vegetables*; Yildiz, F., Wiley, R., Eds.; Food Engineering Series; Springer: Boston, MA, USA, 2017; pp. 403–432, ISBN 978-1-4939-7018-6.
5. Cuong, D.M.; Kwon, S.-J.; Van Nguyen, B.; Chun, S.V.; Kim, J.K.; Un Park, S. Effect of Salinity Stress on Phenylpropanoid Genes Expression and Related Gene Expression in Wheat Sprout. *Agronomy* **2020**, *10*, 390. [CrossRef]
6. Martínez-Zamora, L.; Castillejo, N.; Gómez, P.A.; Artés-Hernández, F. Amelioration Effect of LED Lighting in the Bioactive Compounds Synthesis during Carrot Sprouting. *Agronomy* **2021**, *11*, 304. [CrossRef]

7. Kim, Y.-J.; Loan Nguyen, T.K.; Oh, M.-M. Growth and Ginsenosides Content of Ginseng Sprouts According to LED-Based Light Quality Changes. *Agronomy* **2020**, *10*, 1979. [CrossRef]
8. Kyriacou, M.C.; De Pascale, S.; Kyratzis, A.; Rouphael, Y. Microgreens as a Component of Space Life Support Systems: A Cornucopia of Functional Food. *Front. Plant Sci.* **2017**, *8*, 1587. [CrossRef] [PubMed]
9. Kyriacou, M.C.; El-Nakhel, C.; Graziani, G.; Pannico, A.; Soteriou, G.A.; Giordano, M.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Functional Quality in Novel Food Sources: Genotypic Variation in the Nutritive and Phytochemical Composition of Thirteen Microgreens Species. *Food Chem.* **2019**, *277*, 107–118. [CrossRef] [PubMed]
10. Kyriacou, M.C.; El-Nakhel, C.; Pannico, A.; Graziani, G.; Soteriou, G.A.; Giordano, M.; Zarrelli, A.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Genotype-Specific Modulatory Effects of Select Spectral Bandwidths on the Nutritive and Phytochemical Composition of Microgreens. *Front. Plant Sci.* **2019**, *10*, 1501. [CrossRef]
11. Pannico, A.; Graziani, G.; El-Nakhel, C.; Giordano, M.; Ritieni, A.; Kyriacou, M.C.; Rouphael, Y. Nutritional Stress Suppresses Nitrate Content and Positively Impacts Ascorbic Acid Concentration and Phenolic Acids Profile of Lettuce Microgreens. *Italus Hortus* **2020**, *27*, 41–52. [CrossRef]
12. El-Nakhel, C.; Pannico, A.; Graziani, G.; Kyriacou, M.C.; Gaspari, A.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Nutrient Supplementation Configures the Bioactive Profile and Production Characteristics of Three *Brassica* L. Microgreens Species Grown in Peat-Based Media. *Agronomy* **2021**, *11*, 346. [CrossRef]
13. Keutgen, N.; Hausknecht, M.; Tomaszewska-Sowa, M.; Keutgen, A.J. Nutritional and Sensory Quality of Two Types of Cress Microgreens Depending on the Mineral Nutrition. *Agronomy* **2021**, *11*, 1110. [CrossRef]
14. Caracciolo, F.; El-Nakhel, C.; Raimondo, M.; Kyriacou, M.C.; Cembalo, L.; De Pascale, S.; Rouphael, Y. Sensory Attributes and Consumer Acceptability of 12 Microgreens Species. *Agronomy* **2020**, *10*, 1043. [CrossRef]
15. Rouphael, Y.; Kyriacou, M.C.; Petropoulos, S.A.; De Pascale, S.; Colla, G. Improving vegetable quality in controlled environments. *Sci. Hortic.* **2018**, *234*, 275–289. [CrossRef]
16. Pannico, A.; El-Nakhel, C.; Graziani, G.; Kyriacou, M.C.; Giordano, M.; Soteriou, G.A.; Zarrelli, A.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Selenium biofortification impacts the nutritive value, polyphenolic content, and bioactive constitution of variable microgreens genotypes. *Antioxidants* **2020**, *9*, 272. [CrossRef] [PubMed]
17. Puccinelli, M.; Pezzarossa, B.; Pintimalli, L.; Malorgio, F. Selenium Biofortification of Three Wild Species, *Rumex acetosa* L., *Plantago coronopus* L., and *Portulaca oleracea* L., Grown as Microgreens. *Agronomy* **2021**, *11*, 1155. [CrossRef]
18. El-Nakhel, C.; Pannico, A.; Graziani, G.; Kyriacou, M.C.; Giordano, M.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Variation in macronutrient content, phytochemical constitution and in vitro antioxidant capacity of green and red butterhead lettuce dictated by dierent developmental stages of harvest maturity. *Antioxidants* **2020**, *9*, 300. [CrossRef] [PubMed]
19. Di Bella, M.C.; Niklas, A.; Toscano, S.; Picchi, V.; Romano, D.; Lo Scalzo, R.; Branca, F. Morphometric Characteristics, Polyphenols and Ascorbic Acid Variation in Brassica oleracea L. Novel Foods: Sprouts, Microgreens and Baby Leaves. *Agronomy* **2020**, *10*, 782. [CrossRef]
20. El-Nakhel, C.; Pannico, A.; Graziani, G.; Giordano, M.; Kyriacou, M.C.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Mineral and Antioxidant Attributes of *Petroselinum crispum* at Different Stages of Ontogeny: Microgreens vs. Baby Greens. *Agronomy* **2021**, *11*, 857. [CrossRef]
21. Galieni, A.; Falcinelli, B.; Stagnari, F.; Datti, A.; Benincasa, P. Sprouts and Microgreens: Trends, Opportunities, and Horizons for Novel Research. *Agronomy* **2020**, *10*, 1424. [CrossRef]