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Review

Overview on bioactive compounds' profile of Brassicaceae microgreens: An approach on different production systems and the use of elicitors

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ABSTRACT

We investigated the literature to find the bioactive compounds' profile of Brassicaceae microgreens and the influence of different production systems and the elicitors use in its overall quality. For this, a summary of the latest progress in bioactive compounds qualification and quantification are presented in the relevant databases. Determining the exact role of production systems is not a straightforward process, although it seems to have greater influence according to the intended plant. From the nutritional point of view, the microgreens production demonstrates a high content of bioactive compounds. The use of elicitors, as one of the dependent variables, appears to increase the concentrations of bioactive compounds, especially the use of the light. Besides that, the conditions of growth, harvest and processing remain crucial factors that should be considered in the successful development of the seed.

Keywords: young leaves; phytochemical profile; brassicas; seed; growth conditions.

Introduction

Microgreens are young leafy vegetables, harvested when the first cotyledons expand completely and usually before the real leaves appear. This crop has a fast production cycle, from one to three weeks (Kopsell *et al.* 2012), and can be produced in greenhouses, in the soil or, more commonly, in soilless systems (Di Gioia *et al.* 2015). These characteristics demonstrate the potential of these leafy vegetables to adapt production to a smaller scale and, consequently, to spread their consumption more widely (Kyriacou *et al.* 2016).

In addition to being produced quickly, easily and economically due to the simple equipment and supplies requirements, microgreens also have an advantage from the sustainability perspective (Galieni *et al.* 2020): most cultures demand few resources, such as water or energy

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and no fertilizer, as the seed provides adequate nutrition for the plant (Xiao *et al.* 2015; Weber 2017).

Is the Brassicaceae family, composed mainly of floral and leafy cruciferous vegetables, which is the most consumed plant family worldwide, due to its characteristic flavor and known functional properties, which are directly related to its phytochemical composition (Xiao *et al.* 2019). Several authors have reported that these vegetables are characterized by a higher concentration of bioactive compounds than those of the same species when harvested in the standard growth stage, and therefore could be considered as a functional food (Xiao *et al.* 2012; Ebert *et al.* 2014; Mir *et al.* 2016; Verlinden 2019).

Based on the literature, differences in the phytochemical's concentrations, which potentially produce healthy effects, can be founded when comparing young and mature parts of the same plant. In mature vegetables, the distribution of bioactive compounds may differ according to the specific part of the plant considered (Tomas *et al.* 2021). In the case of microgreens, they are still living tissues after harvest and continue their biological processes, such as transpiration and respiration (Liu *et al.* 2020). Furthermore, as the development of the vegetable epidermis is minimal in microgreens, the bioactive compounds bioavailability is higher than in mature stages (Choe *et al.* 2018).Therefore, the aim of this work is investigating the literature to find the bioactive compounds' profile of Brassicaceae microgreens and the influence of different production systems and the use of elicitors in its overall quality.

Search strategy

This review was reported following the PRISMA recommendation (Aguiar *et al.* 2018). This study included articles from scientific journals that evaluated phytochemical composition of Brassicaceae microgreens over the past ten years in English, Portuguese and Spanish. Experimental studies that evaluated biochemically microgreens from the Brassicaceae family were added or any type of descriptive analysis on the subject were included (Figure 1). The following measures were applied as exclusion criteria: 1) patents, quotations, letters, conference abstracts, case reports; 2) studies that used only microgreens from another family; 3) studies which were not evaluated bioactive compounds; 4) studies that used microgreens for the production of foods.

Detailed individual search strategies were developed for each of the following databases: Food Science and Technology Abstracts (FSTA), Science Direct and Web of Science. Appropriate combinations of words were selected and adapted for research in each database. All references were managed by Mendeley desktop software version 1.17.11 and duplicate articles were removed.

The selection of the studies was completed in 2 steps (Figure 2). In step 1, two researchers independently identified the articles that followed the inclusion criteria and discarded the others. In step 2, the same reviewers checked the methodology of the articles. Finally, the articles

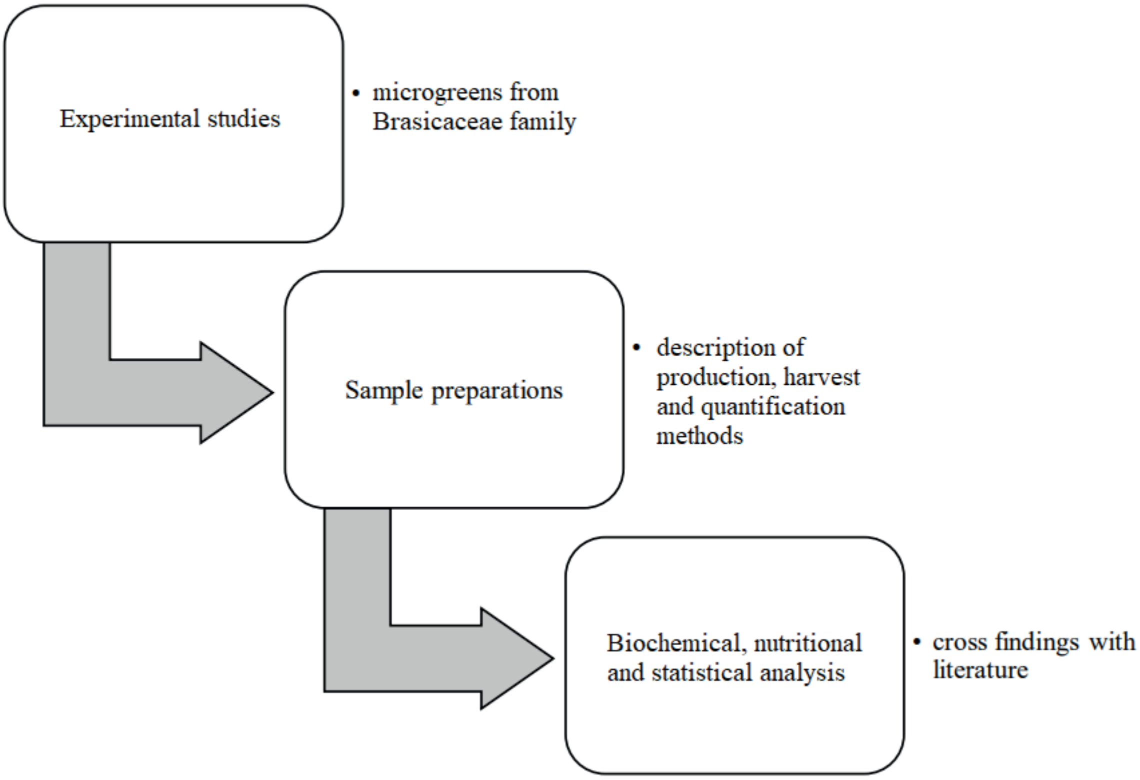

Figure 1. Organization of the study proposal for the quality assessment of Brassicaceae microgreens.

that fulfilled the two steps were included. The reference list of selected studies was critically evaluated by the reviewers. Any disagreement in the first or second phase was decided by discussion until agreement was reached between the reviewers.

Influence of production systems and the use of elicitors

The microgreen's production is usually carried out in a controlled environment, inside greenhouses, using soilless cultivation systems (Di Gioia *et al.* 2017; Liu *et al.* 2020). Choosing a culture medium with adequate microbiological characteristics, as well as the humidity and insects' control, is extremely important to ensure a safe microgreens consumption, as the chosen medium can represent a contamination source (Di Gioia *et al.* 2016).

Available to consumers in supermarket chains as well as on local farms, the microgreens growth environments are quite different: On a local farm, these vegetables are generally grown in the soil, while for the supermarket they are grown hydroponically, which increases productivity, but can compromise nutritional and sensory quality due to longer transport and storage (Tan *et al.* 2019).

In the study by Fortunã *et al.* (2018), there is a variation in the mineral content, depending on the production system. The main difference between these systems, with regard to mineral nutrition, is related to the soil matrix influence, which can change mineral availability.

Internal cultivation and greenhouse systems not only allow significantly higher yields (up to 30% increase) compared to open field systems, but can also facilitate off-season production and substantial chemical composition and bioactive profile manipulation of the final product. Vegetable production in a hydroponic crop appears to be an effective tool for increasing the phytochemicals content, according to the studies reviewed, as well as to control the antinutrients accumulation, such as nitrates (Rouphael *et al.* 2018). As reported by these authors, the combination of genotype, substrate and the environmental conditions management can maximize product quality in a controlled environment.

Compared to traditional soil cultivation, soilless cultivation systems offer the opportunity to standardize the production process in order to achieve faster growth, all year round and with greater efficiency in water and nutrients use. In addition, these systems provide the possibility to regulate secondary metabolism through adequate composition and concentration control of the nutrient solution (Borgognone *et al.* 2016) and

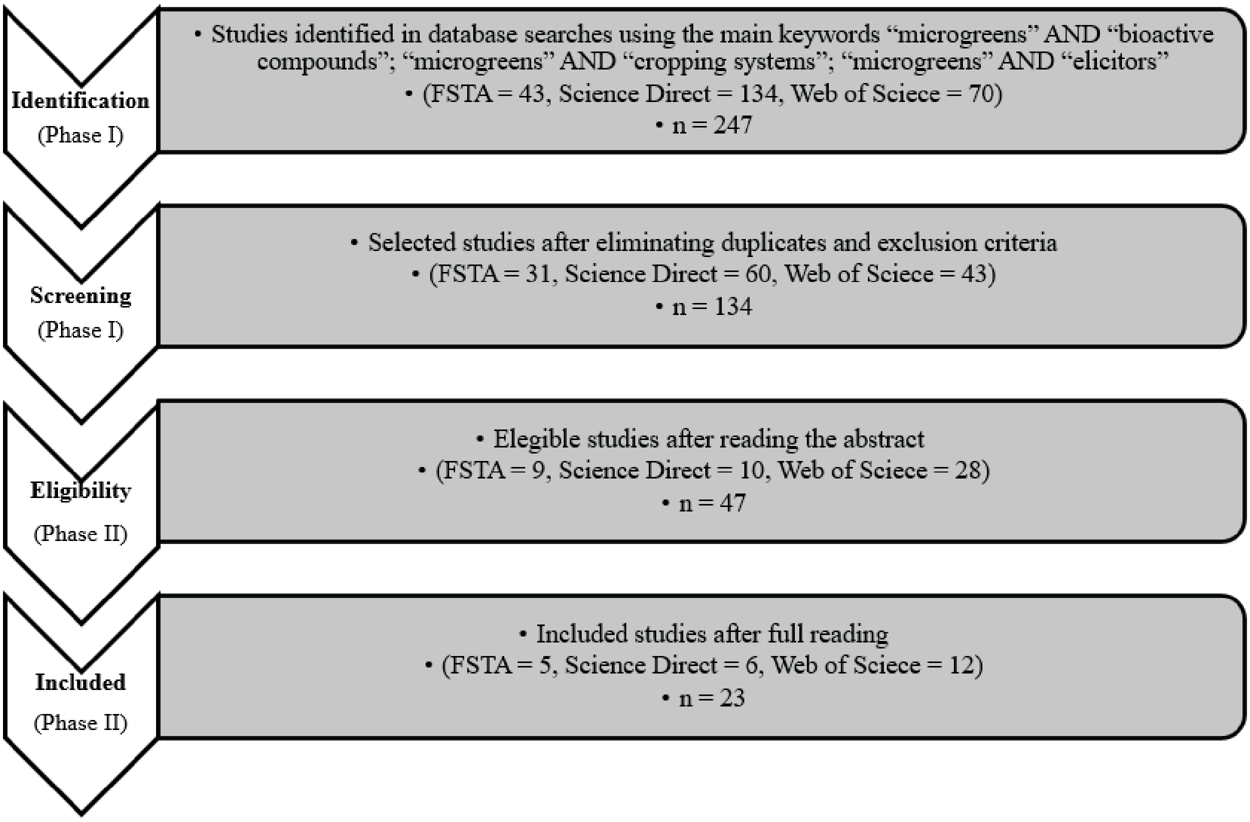

Figure 2. Flowchart of the selection of articles analyzed in this review.

to adapt the production organically to the domestic scale (Kyriacou *et al.* 2016).The influence of different agronomic practices or environmental stresses on secondary metabolites can be modified by the effects of potential others covariates, such as soil type, irrigation water, season of the year, temperature, insects, seed disinfection, handling and post-harvest procedures (Riggio *et al.* 2019). As the time between sowing and harvesting microgreens differs between species (Kyriacou *et al.* 2018), growers should select crops that have a similar growth rate so that the crop can be harvested all at once (Ebert *et al.* 2014).

According to Galieni *et al.* (2020), any stressing condition during germination can work as an elicitor, i.e., it may stimulate secondary metabolisms and increase the phytochemical content of microgreens. Thus, several studies aim to apply abiotic elicitors, such as LED light, and biotics, such as plant hormones, in order to expand, consequently, health benefits (Samuolienė *et al.* 2013; Franco *et al.* 2016; Renna *et al.* 2016; Baenas *et al.* 2019; Yadav *et al.* 2019; Ramirez *et al.* 2020).

One of the benefits of using light as an elicitor is the possibility of selecting different qualities and intensities that will act on the morphology of plants and, consequently, on the synthesis of phytochemicals (Craver *et al.* 2017). On the other hand, exposure to light during storage had no effect on α-tocopherol or total phenolic compounds concentrations, but accelerated the deterioration of sensory quality. Storage in the dark resulted in greater capacity for eliminating hydroxyl radicals and retaining carotenoids (Xiao *et al.* 2014). According to Brazaitytė *et al.* (2015), the spectral quality of light regulation depends on the species and can change the content of bioactive compounds.

As for biofortification, the Brassicaceae species that grow in soilless systems are good candidates for producing mineral-fortified microgreens, when the nutrient solution composition is adjusted. This strategy depends on the appropriate crops' selection and the biofortification process standardization, in order to guarantee a high quality and safe vegetable for consumption (Di Gioia *et al.* 2019; Pannico *et al.* 2020).

In relation to fertilizers, they have been used for a long time to provide essential nutrients for plant growth. Murphy *et al.* (2010) found that calcium nitrate, ammonium nitrate and urea influenced a greater microgreens fresh weight. Sun *et al.* (2015) reported the potential effect of calcium chloride on the nutritional value of microgreens, when they verified an increase in the glucosinolates concentrations.

Among plant hormones, methyl-jasmonate has been applied to increase the bioactive compounds content (Zhu *et al.* 2019; Nuñez-Gómez *et al.* 2020). For Baenas *et al.* (2014), the effect of phytohormones throughout the germination with salicylic acid caused a 20% increase in the total of broccoli and radish glucosinolates. Phytohormones interact in the defense signaling genes expression, being accumulated after pathogenic or environmental stresses. The use of this type of elicitor is due to its ability to simulate the responses of the plant's defense, which lead to bioactive compounds production (Poulev *et al.* 2003). In the last decade, the scientific literature on microgreens has increased. Studies published in recent years demonstrate the nutritional potential of these young plants that can be influenced by production systems and growth conditions for a successful harvest (Figure 3). They also demonstrated that, instead of isolated supplementation of these nutrients, the human body takes better advantage of the interactions of these phytochemicals in their different sources of origin (Liu 2013; Choe *et al.* 2018).

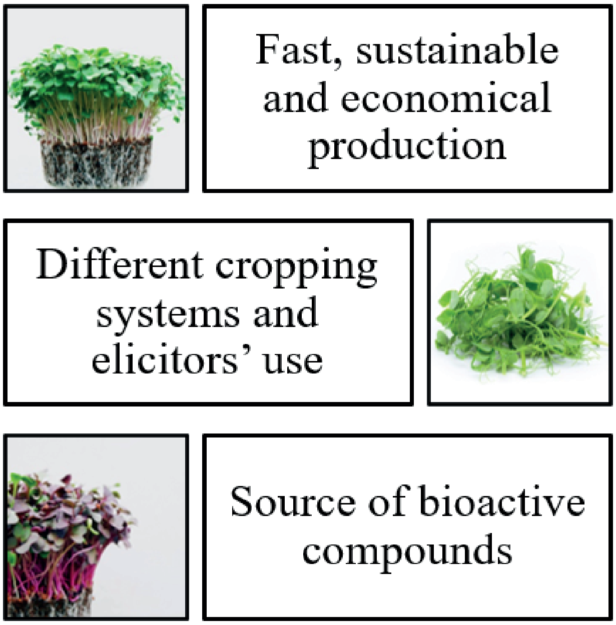

Figure 3. Highlights of microgreens' production.

Characterization of bioactive compounds from microgreens

There are aspects that have been little explored about microgreens, as gathering information about the bioactive compounds' profile of whole Brassicaceae family and not just some members (Galieni *et al.* 2020). In this sense, Table 1 shows the secondary metabolites' characterization and quantification of this family.

The contribution of microgreens to health can be attributed to their antioxidant capacity, in addition to a wide range of nutrients and bioactive components, such as: vitamins (mainly K, C and E), carotenoids, polyphenols and glucosinolates (Choe *et al.* 2018).

The bioactive compounds present in the microgreens are variable and influenced by the growth conditions, harvest and processing (Sun *et al.* 2013; Argento *et al.* 2019).

Table 1. Characteristics of microgreens studies in the Brassicaceae family.

Brassicaceae microgreens	Findings	Reference
Mustard (*Brassica juncea* L. Czern)	463 µmol m-2s-1 of light intensity resulted in an increased of β-carotene, neoxanthin and chlorophyll concentrations and a decreased of zeaxanthin and anteraxanthin.	Kopsell *et al.* (2012)
Arugula (*Eruca sativa* Mill) China rose radish (*Raphanus sativus* L.) Green daikon radish (*Raphanus sativus* L. var. *longipinnatus*) Mizuna (*Brassica rapa* L. ssp. *nipposinica*) Opal radish (*Raphanus sativus* L.) Peppercress (*Lepidium bonariense* L.) Nutrient purple kohlrabi (*Brassica oleracea* L. var. *gongylodes*) Purple mustard (*Brassica juncea* L. Czern) Red cabbage (*Brassica oleracea* L. var. *capitata*) Red mustard (*Brassica juncea* L. *Czern*) Wasabi (*Wasabia japonica* Matsum)	Red cabbage and green daikon radish had the highest ascorbic acid, carotenoids, phylloquinones and tocopherols concentrations.	Xiao *et al.* (2012)
Kohlrabi (*Brassica oleracea* var. *gongylodes*, ‘Delicacy Purple’) Mustard (*Brassica juncea* L., ‘Red Lion’) Red pak choi (*Brassica rapa* var. *chinensis*, ‘Rubi F1’) Tatsoi (*Brassica rapa* var. *rosularis*)	Intermediate light intensities (440 e 330 µmol m-2s-1) increased antioxidant capacity, anthocyanins and total phenolics and decreased nitrate levels.	Samuolienė *et al.* (2013)
Daikon radish (*Raphanus sativus* var. *longipinnatus*)	Exposure to light during storage increased the ascorbic acid concentration. On the other hand, storage in the dark helped to preserve quality and prolong shelf life, with higher b-carotene, lutein/zeaxanthin levels and antioxidant activity. No significant differences in the α-tocopherol and total phenolics concentrations were found.	Xiao *et al.* (2014)
Mustard (*Brassica juncea* L., *‘Red Lion’*) Red pak choi (*Brassica rapa* var. *chinensis*, ‘Rubi F1’) Tatsoi (*Brassica rapa* var. *rosularis*)	Intermediate light intensities (440 e 330 µmol m-2s-1) increased the carotenoids content, especially α-carotene and lutein/zeaxanthin levels.	Brazaitytė *et al.* (2015)
Broccoli (*Brassica oleracea* L. var. *italica*) Radish (*Raphanus sativus* cv. *rambo*)	The storage temperature influenced the quality and the bioactive compounds content. Storage at 5 °C is the most suitable. These crucifers remain acceptable for consumption after the 14-day storage period.	Baenas *et al.* (2017)
Kohlrabi (*Brassica oleracea* var. *gongylodes*) Mustard (*Brassica juncea,* ‘Garnet Giant’) Mizuna (*Brassica rapa* var. *japonica*)	Increasing light intensity increased anthocyanin content and decreased carotenoid concentration. In addition, the light quality affected the chlorophyll and total phenolic concentrations.	Craver *et al.* (2017)
Cress (*Lepidium sativum* cv. Curled) Kohlrabi (*Brassica oleracea* var. *gongylodes*) Komatsuna *(Brassica rapa var. perviridis)* Mibuna *(Brassica rapa var. laciniifolia)* Mustard (*Brassica juncea* L. Czern) Pak choi (*Brassica rapa* L.) Radish (*Raphanus sativus* L.) Tatsoi (*Brassica rapa* var. *rosularis*)	The bioactive compounds content, especially minerals, carotenoids, chlorophyll, antioxidant capacity and ascorbic acid, suffered variations among species.	Kyriacou *et al.* (2018)
Mustard (*Brassica juncea* L. Czern) Leaf mustard *(Brassica juncea* subsp. *integrifolia)* Radish (*Raphanus sativus* L.) Cabbage (*Brassica oleracea L.* var. *capitata*)	On the 1st day of harvest, the species showed the highest total chlorophyll, ß-carotene, lycopene, ascorbic acid levels and the best antioxidant activity, while these substances deteriorated significantly on the 3rd or the 5th day of harvest.	Polash *et al.* (2018)
Mustard (*Brassica juncea* L. Czern)	The total phenolic, minerals and α-tocopherol content increased mainly under UV-A 402 nm, while the nitrate level increased under UV-A 366 and 390 nm. The lutein/zeaxanthin and β-carotene concentrations increased regardless of the wavelength and the time of exposure to light.	Brazaitytė *et al.* (2019)

Table 1. Cont.

Brassicaceae microgreens	Findings	Reference
Broccoli (*Brassica oleracea* L. var. *italica* Plenck) Green curly kale (*Brassica oleracea* var. *sabellica* L.) Red mustard (*Brassica juncea* L. Czern) Radish (*Raphanus sativus* L.)	Compared to their mature counterparts, microgreens are, in general, good minerals and antioxidant sources. They also contain relevant ascorbic acid content and carotenoids levels.	De La Fuente *et al.* (2019)
Mizuna (*Brassica rapa* var. *japonica* cv. Greens) Cress (*Lepidium sativum* cv. Curled)	In general, blue light increased the mineral content of microgreens, with variations among species. Monochromatic lights generated more quantifications of phenolic compounds and total phenolic in mizuna. But dichromatic light increased antioxidant capacity and lutein/zeaxanthin levels in cress. Variations in chlorophyll content within the Brassicaceae family were found. Probably due to differences in pigmentation in the microgreens leaves	Kyriacou *et al.* (2019)
Kohlrabi (*Brassica oleracea* var. *gongylodes*) Broccoli (*Brassica oleracea*) Mizuna (*Brassica rapa* var. *japonica*)	The different qualities of light and wavelengths influenced the concentration of ascorbic acid and the β-carotene among the species.	Samuolienė *et al.* (2019)
Broccoli (*Brassica oleracea* L.)	Microgreens from local farm had higher levels of chlorophyll and ascorbic acid. No significant difference in total phenolic concentration and the antioxidant capacity was found independent of the cultivation system.	Tan *et al.* (2019)
Arugula (*Eruca sativa* Mill) Broccoli (*Brassica oleracea* L. var. *italica*) Brussel sprouts (*Brassica oleracea* L. var. *gemmifera*) Cabbage chinese (*Brassica rapa* L. var. *pekinensis*) Cabbage green (*Brassica oleracea* L. var. *capitata f. alba*) Cabbage red (*Brassica oleracea* L. var. *capitata f. rubra*) Cabbage savoy (*Brassica oleracea* L. var. *capitata f. sabauda*) Cauliflower (*Brassica oleracea* L. var. *botrytis*) Collard (*Brassica oleracea* L. var. *viridis*) Kale chinese (*Brassica oleracea* L. var. *alboglabra*) Kale red (*Brassica oleracea* L. var. *acephala*) Kale Tucsan (*Brassica oleracea* L. var. *acephala*) Kohlrabi purple (*Brassica oleracea* L. var. *gongylodes*) Komatsuna red (*Brassica rapa* L. var. *perviridis*) Mizuna (*Brassica rapa* L. var. *nipposinica*) Mustard Dijon (*Brassica juncea* L. Czern) Mustard red (*Brassica juncea* L. Czern.) Pak choi (*Brassica rapa* L. var. *chinensis*) Peppercress (*Lepidium bonariense*) Radish China rose (*Raphanus sativus* L.) Radish daikon (*Raphanus sativus* L. var. *longipinnatus*) Radish red (*Raphanus sativus* L.) Radish ruby (*Raphanus sativus* L.) Rapini (*Brassica rapa* L. var. *ruvo*) Rutabaga (*Brassica napus* L. var. *napobrassica*) Tatsoi (*Brassica narinosa* L. var. *rosularis*) Turnip (*Brassica rapa* L. var. *rapa*) Upland cress (*Barbarea verna* (P. Mill.) Aschers) Wasabi (*Wasabia japonica* Matsum.) Watercress (*Nasturtium officinale* L.)	The phytochemicals content and composition varied significantly among and within species. But, Brassicaceae microgreens are good sources of antioxidant phytochemicals. The main carotenoids found in this 30 samples of Brassicaceae microgreens were β-carotene, lutein/zeaxanthin and violaxanthin, with concentrations that varied 2.3, 7.9 and 5.5 times, respectively.	Xiao *et al.* (2019)
Kohlrabi (*Brassica oleracea* var. *gongylodes*) Pak choi (*Brassica rapa* L. subsp. *chinensis*)	Natural fiber substrates, especially peat, had an increased nitrate and minerals concentration compared to synthetic. The chlorophylls, carotenoids and ascorbic acid concentrations were mainly influenced by the species. The variability in the polyphenol content was greater between species (8.85–14.33 mg/kg^{-1}·fw) than between substrates (11.16–13.13 mg/kg^{-1}·fw).	Kyriacou *et al.* (2020)

Table 1. Cont.

Brassicaceae microgreens	Findings	Reference
Broccoli (*Brassica oleracea* var. *italica*) Broccoli raab (*Brassica oleracea* var. *botrytis*) Cauliflower (*Brassica rapa* L. subsp. *sylvestris* L. Janch. var. *esculenta* Hort)	Cauliflower had the highest content of some mineral elements and α-tocopherol.	Palmitessa *et al.* (2020)
Tatsoi (*Brassica rapa* L. subsp. *narinosa*)	The ideal Se dose that guarantees the biofortification effectiveness and improves the bioactive compounds content was 16 μM.	Pannico *et al.* (2020)
Broccoli (*Brassica oleracea* var. *italica*) Broccoli raab (*Brassica oleracea* var. *botrytis*) Cauliflower (*Brassica rapa* L. subsp. *sylvestris* L. Janch. var. *esculenta* Hort)	Microgreens showed a higher Nutrient Quality Score (NQS) than their mature counterpart, with emphasis on the cauliflower microgreens score, which was about six times higher. Effectiveness of the NQS in distinguishing differences in general nutritional quality terms, not only between different cultivation conditions, but also when comparing genotypes.	Renna *et al.* (2020)
Arugula (*Diplotaxis tenuifolia* (Wild Rocket Napoli)) Cabbage (*Brassica oleracea* var. *capitata* (Green Cabbage Copenhagen)) Brussels sprouts (*Brassica oleracea* var. *gemmifera* (Green Brussels sprouts Mezzo Nano))	The absence of nutritional supplementation did not increase the content of bioactive compounds in brussels sprouts, but for cabbage microgreens yes, with an increase in total ascorbic acid and anthocyanins. For arugula, there was an increase in the carotenoids, total ascorbic acid and anthocyanins levels, but caused a decrease in total phenolic acids.	El-Nakhel *et al.* (2021)
Arugula (*Eruca sativa* (L.) Cav.) Broccoli (*Brassica oleracea* L. var. italica) Red cabbage (*Brassica oleracea* L. var. capitata)	Broccoli microgreens had more than twice the number of bioactive compounds than their mature counterpart, most of which consisted of lipids, phenolic compounds and alkaloids.	Johnson *et al.* (2021)
Brócolis (*Brassica oleracea* L.), Daikon (*Raphanus raphanistrum* subsp. *sativus* (L.) Domin), Mustard (*Brassica juncea* (L.) Czern.) Rocket (*Eruca vesicaria* (L.) Cav.) Watercress (*Nasturtium officinale* R. Br.)	Broccoli microgreens showed the highest polyphenols, carotenoids and chlorophyll levels, in addition to good antioxidant capacity. Mustard was characterized by a high ascorbic acid and total sugar content. In contrast, the rocket microgreens exhibited the least antioxidant activity.	Marchioni *et al.* (2021)
Kale (*Brassica oleracea L.* var. *acephala)* Kohlrabi (*Brassica oleracea L.* var. *gongylodes*) Cabbage (*Brassica oleracea L.* var. *capitata*) Radish (*Raphanus sativus* L.)	470 phytochemicals were found in the four microgreens of Brassicaceae. Among polyphenols, flavonoids were the most represented class. Glucosinolate bioaccessibility differed significantly between species.	Tomas *et al.* (2021)

To compare profiles of a compound from the same family, cultivation and extraction and detection techniques should be considered (Ramirez *et al.* 2020).

The divergences found in the bioactive compounds' concentrations between microgreens and their mature counterparts are due to two main reasons: 1) microgreens do not undergo post-harvest treatments, therefore they do not undergo nutrient degradation and 2) the germination stage, in which physiological, biochemical and nutritional changes occur, due to the activation of enzymes (Di Gioia *et al.* 2016; Choe *et al.* 2018; Yadav *et al.* 2019; Liu *et al.* 2020).

During germination, some reserve materials of the seeds are degraded and used for respiration and synthesis of new cellular constituents in the developing embryo, causing significant alterations in the biochemical, nutritional and sensory characteristics (López-Amorós *et al.* 2006; Zhang *et al.* 2015). The activation of proteases, which help in the metabolization of proteins, increasing the bioavailability of nutrients, and other changes contribute to the increase in the metabolic activity of the seeds and, consequently, the increase in the bioactive compounds' concentration (Sibian *et al.* 2017).

Regarding the high respiratory and metabolic activity found in tissues with rapid growth and differentiation of microgreens, even minimal differences in the ontogeny stages in the harvest can detain disparate states of transient phenylpropanoid components, thus introducing qualitative variation in polyphenolic profiles, as well as affect its bioavailability and antioxidant potential (Dhuique-Mayer *et al.* 2009; Kyriacou *et al.* 2016; Ebert *et al.* 2017).

Leafy Vegetables

This section is focused on results found for leafy vegetables of Brassicaceae family about their phytochemical content. It was found that mustard was the most studied microgreen by the authors so far.

In the study by El-Nakhel *et al.* (2021), the nutrient supplementation absence elicited an extensive increase in secondary metabolite of arugula, as lutein (110%), β-carotene (30%), the total ascorbic acid (58%) and anthocyanins (20%), but it caused a decrease in total phenolic acids. According to these authors, the microgreens cultivation on a commercial peat-based substrate without nutrient supplementation may be feasible for certain species.

For De la Fuente *et al.* (2019), mustard obtained the highest value of total anthocyanin content (36.4 mg of cyanidin-3-glycoside/100 g·dw), with statistical difference for the other evaluated vegetables. As for the soluble polyphenols content in the bioaccessible fraction, the lowest amount was observed in mustard (821 mg/100 g·dw). According to the authors, this decrease may be due to the slightly alkaline conditions reached after the intestinal phase, together with possible interactions with digestive enzymes.

Polash *et al.* (2018) demonstrated that the mustard microgreens showed the maximum of bioactive substances such as total chlorophyll (8.22 mg/100 g), ß-carotene (2.41 mg/100 g), lycopene (4.37 mg/100 g), ascorbic acid (16.23 mg/100 g) and antioxidant activity (DPPH) (0.75 μg/mL) on the harvest first day. The authors conclude that the microgreens consumption immediately after harvest is the best time to obtain the expected health benefits.

An explanation for the bioactive substances' degradation would be the need for an adequate minerals supply, water and light influx, responsible for various physiological and biochemical reactions and for maintaining the plants enzymatic activity. If any of these variables are not met, physiological and biochemical reactions end up leading to no production and/or degradation of these compounds in an attempt to survive. Instead of performing photosynthesis, the harvested microgreens start to produce toxic pigments and reactive oxygen species (Polash *et al.* 2018).

Regarding antioxidant activity, for Kyriacou *et al.* (2019) both lipophilic and hydrophilic activity, showed higher value in Brassicaceae species. According to the researchers, combined blue light is generally more effective than monochromatic blue or red light in increasing the lipophilic antioxidant capacity of most species (Marchioni *et al.* 2021). The photoreceptors combined activation by LED lights would be able to influence the enzymatic activities regulation responsible for the secondary metabolites' biosynthesis (Alrifai *et al.* 2019).

Floral Vegetables

Kohlrabi and cabbage and their varieties were the most studied microgreens by the authors of this review. His findings for these and other floral vegetables from the Brassicaceae family on bioactive compounds are described below.

In relation to the antioxidant capacity, for Tomas *et al.* (2021), radish purple microgreens showed increased antioxidant activity by the CUPRAC (6694.2 mg TE/100 g·dw) method, with a statistically significant difference for kohlrabi and red cabbage. For De la Fuente *et al.* (2019), the radish showed higher total content (488.65 μM Trolox Eq/100 g) and higher bioaccessible fraction (137.70 μM Trolox Eq/100 g), this, with a significant difference, using the TEAC method.

The differences between the methodologies may be related to the compounds formed after the digestion process, which are susceptible to various reactions with substrates and free radicals according to each antioxidant method, depending on the matrix. The decrease in antioxidant capacity observed in both methods after digestion in vitro is attributable to the bioactive compounds' reduction (De La Fuente *et al.* 2019).

Tan *et al.* (2019) evaluated the bioactive compounds of broccoli microgreens grown by different methods (hydroponically vs. soil cultivation) and from different sources (commercial vs. local farm). A significantly higher chlorophyll concentration was found in hydroponic system and in the soil (0.33 and 0.30 mg/g, respectively) compared to commercial one (0.029 mg/g). The explanation for this difference is that commercial samples may have been taken before the cotyledon leaves development, where chlorophyll accumulates and/or chlorophyll may have been degraded due to the long supply chain and the storage time, deteriorating the vegetable freshness. The result for the total chlorophyll content was fifteen times higher than the stipulated for mature broccoli (Tan *et al.* 2019).

Conclusions

While determining the exact production systems role is not a straightforward process, although it seems to have greater influence according to the intended plant, from a biochemical point of view, the microgreens production demonstrates a high bioactive compounds content and a good source of food health for human diet. The use of elicitors, mostly artificial light, as one of the dependent variables, appear to increase the concentrations of bioactive compounds. Furthermore, it was evident that, more than the family or even the species, it is the seed genotype and the conditions of growth, harvest and processing that will determine the plantation success. For the dissemination of its consumption as a viable vegetable alternative, it is necessary to understand these mechanisms, in order to improve its production technique.

Author Contributions

M. R. Komeroski designed the study, discussed the results and wrote the manuscript. A. R. de Oliveira had the conception of the idea and discussed the results. S. H. Flôres interpreted and discussed results. T. V. Klug found materials and discussed the results.

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