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Revealing the power of green leafy vegetables: Cultivating diversity for health, environmental benefits, and sustainability

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ABSTRACT

In the realm of global diets, green leafy vegetables are recognized for their culinary flexibility and nutritional value. This paper presents a thorough investigation of green leafy plants, exploring their botanical diversity and their impact on health, socio-economic, cultural, and environmental aspects. Beginning with an examination of their taxonomy and current consumption trends, the paper delves into their nutritional benefits, including vitamins, minerals, and antioxidants. Furthermore, it discusses their potential contributions to biodiversity, sustainable agriculture, and environmental resilience. Future perspectives explore technological advances, market dynamics and production sustainability, while considering the impacts of climate change on post-harvest handling. Through interdisciplinary collaboration, the paper provides holistic insights into the implications of green leafy vegetable production and consumption, emphasizing their important role in addressing global challenges in promoting human health and sustainable development. Overall, it advocates for further research, policy initiatives, and collective action to promote the cultivation, consumption, and integration of wider variety of green leafy vegetables into food systems for a healthier and more sustainable future.

1. Short introduction and methodology

Green leafy vegetables (GLVs) are esteemed components of diets worldwide, celebrated for their diverse culinary applications and unparalleled nutritional richness (Aslam et al., 2020). This paper embarks on a comprehensive exploration of GLVs, delving into various dimensions ranging from their botanical overview to their health, socio-economic, cultural, and environmental implications.

Through the meticulous examination, the paper endeavours to provide valuable insights into the multifaceted nature of GLVs and their pivotal role in addressing current challenges covering health, environment, and food security. This paper serves as a bridge between diverse disciplines, weaving together insights from diverse academic realms such as nutrition, medical science, economics, environmental health, sociology, and agriculture. By synthesizing knowledge from these varied fields, the importance of GLVs in our diets is clearly shown. Through this interdisciplinary lens, the study illuminates how our dietary choices impact not only our personal health but also broader socio-cultural dynamics, environmental sustainability, and agricultural practices. By uncovering these intricate connections, the paper offers valuable insights into the role of GLVs in fostering human health, well-being, and sustainable development.

A comprehensive search of databases, including PubMed, Scopus, Web of Science, and Google Scholar, was conducted using the following terms: 'green leafy vegetables', 'nutritional benefits', and 'socio-economic implications'. Inclusion criteria focused on peer-reviewed articles published from 2010 to 2023 to reflect contemporary research and discussions about GLVs in the context of nutrition, food security, and sustainable agriculture. The review highlighted examples from various regions, such as Africa, Europe, and Asia, to illustrate the diverse culinary applications and nutritional contributions of GLVs.

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2. General overview and culinary applications of green and microgreen leafy vegetables

GLVs also called leafy greens or greens, are vegetables characterized by their edible leaves, which can be consumed either raw or cooked/processed (Putriani et al., 2022). These vegetables are essential constituents of a balanced diet, holding significant importance and popularity due to their capacity to offer a diverse array of plants with different characteristics such as colour, taste, and texture, in addition to their high nutritional value (Koukounaras et al., 2020). Among the commonly consumed varieties are spinach, cabbage, kale, swiss chard, collard greens, and romaine lettuce. Alongside popular choices there are also lesser-known greens such as amaranth leaves, rucola, purslane, and lamb's quarters. Additionally, bok choy, turnip greens, and dandelion greens further expand the array of options available (García-Herrera et al., 2020). GLVs encompass not only widely recognized varieties but also underutilized options that offer valuable nutritional benefits. Some examples include dandelion greens, malabar spinach, sorrel, and many others. These underutilized varieties hold unique flavours and textures, contributing to culinary diversity and nutritional richness. Table 1 displays a detailed list of 78GLVs, providing valuable information about their characteristics and nutritional value.

Microgreens, as delineated by their name, are diminutive plants characterized by their tender nature, with 'micro' indicating their small size and 'green' signifying their verdant coloration. Sprouts, microgreens, and baby greens are essentially young and delicate plants harvested at an early stage of growth from various vegetables and consumed before reaching maturity.

Often referred to as 'vegetable confetti', microgreens are youthful, tender greens used to enhance the colour, texture, or flavour profile of dishes (Treadwell et al., 2020). This rise in interest and consumption reflects a growing recognition of the health benefits associated with microgreens, positioning them as a sought-after superfood (Lenzi et al., 2019). Notably, microgreens are esteemed for their exceptional nutritional potential and sensory attributes (Renna and Paradiso, 2020). Microgreens find application not only as flavouring and garnishing agents but also as visual components, owing to their refined textures, flavours, and colours (Treadwell et al., 2020).

GLVs are foundational in global culinary traditions, featured prominently in a variety of dishes. Salads, such as the iconic Caesar salad with romaine lettuce or Mediterranean-inspired versions with spinach and arugula, highlight their freshness and nutritional density (Savo et al., 2019). GLVs are also integral in sandwiches and wraps, enhancing flavour profiles with kale, lettuce, and Swiss chard while providing essential vitamins and minerals (Luczaj et al., 2013). GLVs are most consumed in spring, often boiled and seasoned with olive oil and lemon or used in savoury pies. They are versatile additions to sauces, soups, stews, and stir-fries, adding depth to flavours (Pato, 2010).

A variety of traditional culinary techniques are employed for the preparation of GLVs, reflecting various cultural practices. In the Mediterranean, diverse culinary techniques include boiling, frying with eggs in Italy, and raw consumption with dressing in southern France (Savo et al., 2019; García-Herrera et al., 2020). In Croatia, greens are traditionally boiled for around 30 min and then dressed with olive oil (García-Herrera et al., 2020). Conversely, in Spain, traditional methods for cooking greens involve boiling or frying, sometimes with additional ingredients (Pato, 2010). Various preparation methods like steaming, sautéing, frying, and boiling are historically used for GLVs, impacting their nutritional content (García-Herrera et al., 2020). Despite cooking, GLVs retain folates, vitamin C, and phenolic compounds, with boiling is enhancing mineral bioavailability by reducing oxalic acid (García-Herrera et al., 2020). Traditional cooking methods also mitigate toxins like saponins and triterpene glycosides, enhancing the safety of consuming these greens (García-Herrera et al., 2020).

In conclusion, while cooking leafy green vegetables may reduce certain nutrients, it also helps break down anti-nutritional compounds and toxins found in raw vegetables. Thus, both raw and cooked vegetables offer distinct benefits in the diet. Moreover, incorporating a variety of cooking methods and consuming a balanced mix of raw and cooked leafy greens and microgreens can further enhance the nutritional diversity and overall health benefits obtained from these vegetables.

3. Production and consumption trends of green leafy vegetables

Leafy vegetables, cultivated and consumed across nearly every continent, exhibit a remarkable diversity in types and varieties owing to the unique characteristics of each geographical region. Generally, the production of vegetable is increased globally due to the recognition of the benefits of vegetable consumption and the growth in population especially in urban areas. China stands as one of the leading global producers of GLVs, experiencing rapid growth in vegetable production since the turn of the 21st century. Over the span of two decades, vegetable production increased from 424 million tons to 721 million tons, accompanied by a notable expansion in total sown area from 15.237 thousand hectares to 20.863 thousand hectares between 2000 and 2019 (Liu et al., 2020).

In 2022, fresh vegetable cultivation in Europe covered 2.0 million hectares, yielding 59.8 million tonnes (Eurostat, 2024). Spain led production with 23.7%, followed closely by Italy at 20.8%. In Greece, fruits and fresh vegetables contributed significantly, comprising 31.7% of the agricultural output value (Eurostat, 2024). Specific types of fresh vegetables, including lettuce, spinach, chicory, endives, asparagus, and artichokes, accounted for 18.2% of the EU's harvested production. Globally, the harvested area for primary vegetables tripled between 1961 and 2014 (FAOWHO, 2017).

The global production of major GLVs in 2021 showed a 69% increase from 2000 (FAOSTAT). Fresh leafy vegetables are predominantly sourced locally due to challenges in storage and transportation over long distances, reflecting their perishable nature and local production reliance.

Similarly, the microgreens market has been undergoing noteworthy growth in recent years, with a compound annual growth rate estimated to be around 7–9% globally (Verlinden, 2020). This growth is driven by increasing consumer awareness of the health benefits and culinary versatility of microgreens. Commercially, twenty-five distinct types of microgreens are cultivated globally, with arugula, kale, basil, mustard green and coriander being the most dominant ones (Rizvi et al., 2023).

However, despite an increase in the production, neither the economic nor the nutritional power of green and microgreen leafy vegetables is sufficiently recognized and utilized (Schreinemachers et al., 2018). This suggests a discrepancy between the growing availability of these nutritious crops and their recognition and utilization in both economic and dietary contexts. Such underrecognition may impede efforts to fully exploit the benefits that GLVs offer in terms of food security, economic development, and public health initiatives. Therefore, there is a pressing need for greater awareness and investment in harnessing the full potential of GLVs to address these multifaceted challenges.

The recommended daily intake of vegetables, averaging at least 400 g for adults, helps reduce the risk of non-communicable diseases like cancer, obesity, cardiovascular disease, and type II diabetes (WHO, 2020). Globally, less than half of countries meet this recommendation, with slightly over half of European nations doing so (Stea et al., 2020). Notably, Cyprus, Czech Republic, Finland, Iceland, Moldova, The Netherlands, Norway, Slovakia, and Sweden fall short of this standard, with the Netherlands having the lowest vegetable consumption in Europe. Conversely, southeastern European countries like Albania, Bosnia, Croatia, North Macedonia, and Turkey exceed 200 kg of vegetable consumption annually (Stea et al., 2020).

In 2021, average fruit and vegetable consumption in Europe reached 364.6 g per capita per day, up 2.2% from 2020 to 1.3% from the previous five-year average. In 2019, 67% of EU residents aged 15 and over

Table 1
Green leafy vegetables list.

Scientific name	Common name	Nutritional value	Characteristics	Reference
Amaranthus caudatus	Amaranth, Kiwicha	Source of lysine and other bioactive compounds. Qualitatively and quantitatively superior protein composition than cereals and legumes. Ranked as one of the top five vegetables in antioxidant properties	Resistant to heat, drought, diseases and pests	(Martinez-Lopez et al., 2020)
Amaranthus hybridus	Green amaranth	Source of most of the essential nutrients, with notable amounts of Mg, Ca and dietary fibre	Used for making infusions, salads and soups. Can be mixed with other vegetables or legumes. The use of biostimulants increases the yield and nutritive value of the crop	(Ngoroyemoto et al., 2019)
Amaranthus spinosus	Spiny amaranth-spinach	Source of high levels of available nutrients	Distributed widely over the tropical and subtropical regions, (tropical Africa, Southeast Asia, Americas, temperate Europe). Drought tolerant and generally adapted to harsh environments	(Sarker and Oba, 2019)
Amaranthus tricolor	Amaranth, En choy	Good source of ascorbic acid, vitamin A, dietary fiber and β-carotene. Contains exceptionally high Fe content (15.01 mg/100 g) and high contents of Ca (239 mg/100 g), lysine and methionine, and 3.4 g/100 g of protein. P and K content is similar to common GLVs.	Widely grown in the tropics. Annual, fast growing, and easily cultivated in gardens and fields. One of the most important leafy vegetables in Asia. Extensively acclimated to abiotic stresses, including drought and salinity	(Gupta et al., 2005; Sarker et al., 2022)
Apium graveolens	Celery	Contains necessary nutrients and multiple biologically active ingredients, such as apigenin and terpenoids	Annual or biennial, and salt-tolerant	(Li et al., 2020)
Basella alba, Basella rubra	Malabar spinach	Source of betacyanin, carotenoids, bioflavonoids, β-sitosterol and lupeol with antioxidant, antiproliferative, antimicrobial and anti-inflammatory effects. Similar nutritional and medicinal value to spinach	Extremely heat tolerant and fast-growing perennial vine, cultivated as a cool-season vegetable. Can be used instead of normal spinach	(Chaurasiya et al., 2021)
Beta vulgaris subsp. *maritima*	Wild beet	Source of vitamin E vitamers (α- and γ-tocopherol), vitamin C, citric and oxalic acid, phenolics and flavonoids, α-linolenic, linoleic and palmitic acid	Grows naturally in Mediterranean and northern Europe regions in salt marsh and saline areas	(Petropoulos et al., 2018; Lombardi et al., 2022)
Beta vulgaris var. *cicla*	Swiss chard	Contains secondary metabolites, called betalains and apigenin flavonoids (vitexin, vitexin-2-O-rhamnoside and vitexin-2-O-xyloside), which show antiproliferative activity on cancer cell lines	Can be cultivated in soils with scarce organic material, in summer, spring or winter crops and handles low light and water input	(Ninfali and Angelino, 2013)
Beta vulgaris var. *rubra*	Beet greens	High antioxidant capacity due to catechins, quercetin (5.02 mg/g FW), high amounts of ferulic acid (26.2 mg/100 g FW)	Can be cultivated in soils with scarce organic material and handles low light and water input	(Ninfali and Angelino, 2013; Mazzucotelli et al., 2018)
Boerhaavia diffusa	Punarnava	High Cu (0.22 mg/100 g) and Ca content (330 mg/100 g), 3 g/100 g of protein, P and K content similar to common GLVs. Demonstrates better bioavailability of minerals, higher dietary fiber content than coventional GLVs and has therapeutic potential	Perennial creeping plant, up to 1 m long or more, with spreading branches. Stout and woody roots and thick, fleshy, and hairy leaves	(Gupta et al., 2005; Nayak and Thirunavoukkarasu, 2016)
Borago officinalis	Borage	High concentration of anthocyanins. Contains α-linolenic acid and stearidonic acid, esters of squalene-type triterpene, sterol, flavonoids, coumarins, and tannins and small amounts of pyrrolizidine alkaloids	Hairy annual herb with worldwide distribution. Can be minimally processed to produce detached whole leaves with good quality characteristics. Storage temperature of processed borage leaves at 2 °C can result in 21 days of self life	
Brassica carinata	Ethiopian mustard, Carinata	Source of phenolic compounds and glucosinolates (leaves). Alternative energy source (seeds)	Cultivated as a vegetable in East Africa. Could replace crops that are susceptible to drought and heat, while it can serve as a winter crop. Used also as an oilseed crop especially in the arid and semi-arid areas. Suitable for crop rotation and intercropping with food crops	(Hagos et al., 2020)
Brassica juncea	Indian-Chinese mustard, Mustard greens	Source of alpha−linolenic acid (1.1 mg/g)	Easily cultivable and widely distributed both as a cultivar and transgenic escape in subtropical and temperate climates	(Kumar et al., 2020)
Brassica oleracea var. *acephala*	Kale	Higher Ca, folate, riboflavin, and vitamin K and C content than in other vegetables	Many different varieties that can be cultivated in a wide range of soil types, with optimal production achieved on deep, loamy, low-acid to neutral (pH 6–6.5) soils with proper porosity. Has high demands for nutrient uptake	(Šamec et al., 2019)
Brassica oleracea var. *capitata*	White cabbage	Important source of phytonutrients in the human diet, high fibre and protein content and 692.2 mg/g DW of sinapic acid	Among the world's most commonly cultivated vegetables. Many varieties with different morphological traits, nutritive values, phytochemical composition and tolerance to abiotic and biotic stresses	(Šamec et al., 2017; Mazzucotelli et al., 2018; Kumar et al., 2020)
Brassica oleracea var. *viridis* (acephala)	Collard	Contains free forms of water soluble vitamins (vitamins B1, B2, B3, B5, B6, B9 and C) and fat-soluble vitamins (pro-vitamin A and vitamin E),	Common GLV with fast and easy cultivation in a wide range of soils. Tolerant to abiotic stresses (increased salinity, drought, high and low	(Kumar et al., 2020; Šamec et al., 2019)

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Table 1 (*continued*)

Scientific name	Common name	Nutritional value	Characteristics	Reference
		and has exceptionally high contents of vitamin A and K1 (phylloquinone) and high Ca and folate content	temperatures). High nutrient uptake requirements	
Brassica oleracea var. *alboglabra*	Chinese kale, Kai-Lan	High content of essential micronutrients. Contains (per 100 g) vitamin A (7540 IU), vitamin C (115 mg), Ca (62 mg) and Fe (2.2 mg)	Frost tolerant with evidence of waterlogging intolerance. Different cultivars of chinese kale can be grown successfully in a wide range of climatic conditions	(Issarakraisila et al., 2007; Sagwansupyskorn, 1993)
Brassica rapa subsp. *chinensis*	Bok choi, Pak choi	Good source of vitamins and minerals. Contains (per 100 g): water (93 g), protein (1.7 g), fat (0.2 g), carbohydrates (3.1 g), fibre (0.7 g), ash (0.8 g), β-carotene (2.3 mg), vitamin C (53 mg), Ca (102 mg), P (46 mg) and Fe (2.6 mg)	Biennial herb, cultivated as an annual for its immature, fully expanded tender leaves. Used for soups, stir-fried, raw or pickled	(Sagwansupyskorn, 1993)
Brassica rapa subsp. *japonica*	Mizuna	High antioxidant properties. Rich in bioactive substances, vitamins (β-carotene, C, B1, B2, K), minerals, and microelements. Source of I, Ca, folic acid, phenols, and flavonoids.	Density of 90 plants per square meter in soil cultivations. High yields in hydroponic cultures. Able to accumulate 10% more Ca from bio-enriched nutrition solutions	(Tadevosyan, 2020)
Brassica rapa subsp. *pekinensis*	Chinese cabbage	Low in calories (15.5 kcal/100 g). Contains, per 100 g, water 95 g, protein 1.2 g, fat 0.2 g, carbohydrates 2.2 g, fibre 0.5 g, Ca 49 mg, Fe 0.7 mg, vitamin A 0.9 mg, and vitamin C 38 mg	Propagated by seed. Seedlings are used to shorten the cultivation period. Heat-tolerant, tropical varieties and hybrids exist. Heads are harvested when compact	(Sagwansupyskorn, 1993)
Brassica rapa subsp. *rapa*	Turnip greens	Per 100 g, the leaves contain approximately 90 g water, 3 g protein, 0.4 g fat, 5 g carbohydrates, 0–4 g fibre, 4.6 mg β-carotene, 139 mg vitamin C and 28.2 kcal	CLeaves and roots are commonly consumed as a boiled, fried vegetable, in soups and stews or fresh vegetables in salads. The flower buds are also eaten sautéed	(Sagwansupyskorn, 1993)
Brassica rapa subsp. *chinensis* var. *parachinensis*	Choy sum, Caisin	The leaves contain vitamin A, B1, B2, and C, niacin, Ca, Fe, P, K, and Mg. The energy value is 54 kJ/100 g	Evidence of drought tolerance. More tolerant to waterlogging compared to other brassica species. Different cultivars can be grown in a wide range of climatic conditions	(Sagwansupyskorn, 1993; Issarakraisila et al., 2007)
Brassica rapa subsp. *narinosa*	Tatsoi	Soluble sugars, carotenoids, fibre, L-ascorbic acid and chlorophyll a and b	Short cultivation period, very popular GLV in Asian countries. Petioles and leaves can be consumed steamed or fresh. Suitable for summer-autumn field cultivation in Central Europe	(Kalisz, 2013)
Cardiospermum halicacabum	Heart pea	Cyclohexane-1, 4, 5-triol-3-one-1-carboxylic acid, benzene acetic acid, caryophyllene, phytol and neophytadien, alcohols, phenols, alkanes, alkynes, aliphatic ester and flavonoids	Herbaceous climber plant, about 2–4 m long, evergreen, distributed in tropical and subtropical regions of Africa and Asia. Consumed as GLV in India. Antibacterial and antifungal properties	
Celosia argentea	Sokoyokoto	3.2 g of protein per 100 g, P and K content similar to common GLVs, exceptionally high Fe content (13.15 mg/100 g), better bioavailability of minerals and higher dietary fiber content than coventional GLVs	Widely cultivated in tropical and sub-tropical Africa, North America and Asia. Has high economic value and is a source of living for African farmers during the dry season	(Gupta et al., 2005; Eşiyok et al., 2018)
Centella asiatica	Gotu kola, Brahmi	Medicinal properties due to the triterpenoids asiaticoside and madecassoside, asiatic acid and madecassic acid. Rich in vitamins B and C, proteins, carotenoids, minerals, and flavonoids, volatile oils, tannins, and polyphenols	Mainly grown in moist areas, used as a herb	(Sarkar et al., 2023)
Chenopodium album	Bathua, White goosefoot	Contains the essential amino acids lysine, isoleucine, leucine, phenylalanine, tyrosine, threonine, tryptophan, valine, histidine and methionine. Has high protein content, N, P, K, Ca, Mg, Fe and Mn	Salt-tolerant (Mediterranean halophyte), annual broad-leaved. Young shoots and leaves consumed fresh or cooked	(Petropoulos et al., 2018; Kumar et al., 2020)
Chenopodium bonus henricus	Mount spinach	Contains flavonol glycosides of patuletin, 6-methoxykaempferol, and spinacetin and demonstrates neuroprotective and antioxidant activity	Perennial herbaceous plant, spread in mountainous regions and used as a vegetable in some European traditional cuisines	
Chrysanthemum coronarium L. var. *spatiosum*	Tung ho, Garland chrysanthemum	Useful source of several essential oils	The leaves and shoots are consumed	(Alvarez-Castellanos and Pascual-Villalobos, 2003)
Ciccer arietinum	Bengal gram (chickpea leaves)	Good source of ascorbic acid, β-carotene and Fe, and several minerals with higher content than spinach and cabbage	Nitrogen-fixing (legume). The young leaves are used as a GLV in parts of the world	
Cichorium endivia var. *latifolia*	Broad-leaved endive, Escarole	The species contain kaempferol conjugates [kaempferol 3-O-glucoside, kaempferol 3-O-glucuronide and kaempferol 3-O-(6-O-malonyl) glucoside]	Broad, pale green leaves. Less bitter than other endives	(DuPont et al., 2000)
Cichorium intybus	Chicory	Good source of antioxidants. Contains tannins, saponins, flavonoids, terpenoids, cardiac glycosides, and anthocyanins	Widespread. Can tolerate extreme temperatures during both vegetative and reproductive growth. Forms a rosette	(Eşiyok et al., 2018; Ceccanti et al., 2020)
Cichorium spinosum	Spiny cichory	Significant antioxidant activities and liver detoxifying properties. Contains tocopherols and phenolic compounds such as α-tocopherol, γ-tocopherol, 5-O-caffeoylquinic acid, chicoric acid, caftaric acid, kaempferol-3-O-glucuronide, quercetin-3-O-glucuronide, and apigenin-O-	Wild, salt-tolerant Mediterranean halophyte	(Petropoulos et al., 2018)

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Table 1 (*continued*)

Scientific name	Common name	Nutritional value	Characteristics	Reference
		glucuronide, cichoriol A, B, C and D, sesquiterpene lactones and coumarins		
Cleome gynandra	Spider plant, African cabbage	Contains dietary polyphenolic phytochemicals such as flavonoids, essential ions, polyphenols and terpenoids. ascorbic acid, violaxanthin, α and β-carotene, α, β, and γ -tocopherol, β-cryptoxanthin and luteolin, polyunsaturated fatty acids. Rich source of vitamins A and C, protein (23.4%), fibre (8.3%) and Zn. Higher concentrations of Ca, Fe, P, K and vitamin C than commercial vegetables like cabbage and swiss chard	Erect annual herb that could grow up to 1.5 m, strongly branched, with a long taproot. Drought tolerant and capable of growing well in a wide range of climatic and soil conditions	(Mashamaite et al., 2022)
Cocculus hirsutus	Javanada, Patalgarudi	Exceptionaly high carotene content (67 mg/100 g), 3.9 g/100 g of protein, P and K content similar to common GLVs, high content of Cu (0.22 mg/100 g) and dietary fiber (11.08 g/100 g), and better bioavailability of minerals than coventional GLVs	Perennial GLV climber, distributed mostly in tropical and subtropical areas	(Gupta et al., 2005)
Commelina benghalensis	Benghal dayflower, Tropical spiderwort	2.4 g/100 g of protein, P and K content similar to common GLVs. Better bioavailability of minerals and higher dietary fiber content than coventional GLVs	Perennial herb. Young leaves are eaten as vegetables	(Gupta et al., 2005)
Corchorus olitorius	Jute mallow, Nalta jute, Moloha	Rich source of protein, vitamin C, antioxidative compounds, Fe, Ca, thiamin, riboflavin, niacin, dietary fiber, phenolic compounds, polysaccharides, carotenoids and folic acid	Popular summer GLV in African, Asian and Middle Eastern countries. Drought talerant landraces	(Simlai et al., 2014; Bashandy and El-Shaieny, 2021)
Coriandrum sativum	Coriander, Cilantro	Good source of ascorbic acid, β-carotene, Fe and soluble dietary fiber	Salt-tolerant genotypes and high seed and yield genotypes	(Kumar et al., 2020; Aftab et al., 2021)
Crithmum maritimum	Sea fennel	Phenolic compounds, gallic, caffeic, vanillic, rosmarinic, chlorogenic and p-coumaric acid and falcarindiol. Demonstrates diuretic, antiscorbutic, depurative, digestive, purgative, anti-inflammatory, antiplatelet and antimutagenic effects	Salt-tolerant Mediterranean halophyte	(Petropoulos et al., 2018)
Digera arvensis/muricata	Tartara	High levels of protein (4.3 g/100 g), Ca (506 mg/100 g), and exceptionally high Fe content (17.72 mg/100 g). P and K content similar to common GLVs, 17.93 mg/100 g of total carotene and better mineral bioavailability than coventional GLVs	Annual plant of 70 cm height, with differentiated varieties with hairy or broad leaves	(Gupta et al., 2005; Manimekalai et al., 2020)
Diplotaxis tenuifolia	Wild rocket	The leaves contain carotenoids, phenolics, sterols, fatty acids and glucosinolates, important for colorectal cancer prevention	Perennial plant, harvested traditionally from the wild. Increasing importance due to the increased demand of Used in ready-to-use salads	(Ramos-Bueno et al., 2016)
Enhydra fluctuans	Buffalo spinach	Contains antioxidant compounds	Annual, semi-aquatic herbaceous vegetable, distributed in tropical and subtropical regions. Stalkless, serrated leaves, 3–5 cm in length, pointed or blunt at the tip	(Ramjan Ali et al., 2013; Simlai et al., 2014)
Eruca sativa	Rocket	High antioxidant capacity due to catechins, quercetin (14.3 mg/g FW) and sinapic acid (861 mg/g DW)	Increasing production. Suitable for soilless cultivation systems	(Fontana and Nicola, 2009; Mazzucotelli et al., 2018)
Eruca vesicaria	Wild rocket	Medicinal plant with depurative effects. Contains vitamin C and iron, and high amounts of chlorophylls	Cultivated often, mainly as whole leaves 8–12 cm long. Baby leaves have grown in popularity due to the increase of ready-to-eat vegetables. Increased postharvest life due to the very small section only on the petiole	(Egea-Gilabert et al., 2009)
Gynandropsis gynantra/pentaphylla		Protein 3.6 g/100 g, P and K content similar to common GLVs, better bioavailability of minerals than coventional GLVs	Fast-growing GLV, widespread and increasingly valued as a commercial crop in West and Eastern Africa. Well adapted to extreme climatic conditions	(Gupta et al., 2005; Achigan-Dako et al., 2021)
Inula crithmoides	Golden samphire	Hydrocarbons, such as 1-methylethyl-trimethyl-benzene (18.7%), monoterpene hydrocarbons (32.1%), α-pinene, p-cymene, β-phellandrene and α-phellandrene, phenols (19.6%), sesquiterpenes hydrocarbons (19.4%), oxygenated sesquiterpenes, scopoletin (15.3%), phenolic compounds, carotene derivatives and fatty acids	Salt-tolerant (Mediterranean halophyte)	(Petropoulos et al., 2018)
Ipomoea aquatica	Water spinach, Kangkong	Useful source of amino acids and organic extracts. Rich source of K and Ca, vitamins A and C. Energy of only 19 kcal per 100 g	Mainly found in different water bodies such as ponds, stagnant streams, wet paddy fields, or sometimes floating in the water	(Sarkar et al., 2023)
Lactuca sativa	Lettuce	Contains alpha−linolenic acid (0.7 mg/g) and phenolics	Very important leafy vegetable crop with many varieties and traits. Used in human diet for more than 6500 years. Grows best in average temperatures between 15 and 18.5 °C, but can withstand temperatures down to −5 °C.	(Mazzucotelli et al., 2018; Kumar et al., 2020)

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Table 1 (*continued*)

Scientific name	Common name	Nutritional value	Characteristics	Reference
Lactuca serriola	Prickly lettuce	Minerals and vitamins A and C, beta-carotene, 8-deoxylactucin, lacticin, jacquenilin, lactupicrin and ubiquinone. Mild sedative, diuretic, diaphoretic, expectorant and antiseptic effects	World-wide distributed, found in cool and temperate regions, on rich in nutrients soils with alkaline properties	(Eşiyok et al., 2018)
Lemna perpusilla	Duckweed	Provides all the essential amino acids, vitamin E (457 mg/100 g) and has high Zn content (15 mg/100 g)	Aquatic species	(Kumar et al., 2020)
Lepidium latifolium	Pepperwort	Bioactive compounds, various Kaempferol derivatives, glucosinolates, phenols, flavonoids and fatty acids such as linolenic, palmitic and stearic acid	Salt-tolerant (Mediterranean halophyte)	(Petropoulos et al., 2018)
Marsilea minuta	Water clover	Contains phenols, flavonoids, steroids, canthoproteins and proteins	Common Indian hydrophytic species. Grows abundantly in deep water or erect in low water or on land	(Bhadra et al., 2012)
Mentha spicata	Mint	Good source of protein, ascorbic acid, β-carotene and Fe	Cultivated in soil and soilless systems	(Surendran et al., 2016)
Mollugo pentaphylla	African Chickweed	Its major chemical constituents are glycosyl flavine, carotene, mollugenol and mollupentin. Demonstrates anthelmintic activity	Erect herb. The leaves vary in shape and have bitter taste. Traditionally used as a medicinal plant in India	
Ocimum basilicum	Basil	Contains essential oils and aroma compounds. Used in traditional medicines	One of the most popular herbs grown in the world. Grows wildly in tropical and sub-tropical regions. Shows high genetic diversity: at least 65 species of Ocimum and 7 types of commercial cultivars of *Ocimum basilicum*	(Makri and Kintzios, 2008)
Petroselinum crispum	Parsley	Contains phenolics and flavonoids and demonstrates high antioxidant capacity	Common herb native to the Mediterranean region, widely used as a seasoning. Unconventional GLV in salad mixture elaboration. Mainly sensitive to water stress	(Sabry et al., 2016; Mazzucotelli et al., 2018)
Picris hieracioides		Contains ascorbic acid, phenolics, flavonoids, carotenoids and chlorophylls	Biennial or short-lived perennial herb. Forms a rosette	(Ceccanti et al., 2020)
Plantago coronopus		Contains ascorbic acid, phenolics and flavonoids	Salt-tolerant, perennial herb with elongated leaves. Forms a rosette. Demonstrates high antioxidant capacity	(Ceccanti et al., 2020)
Polygala erioptera	Balae	Ascorbic acid (85 mg/100 g), protein (2.2 g/100 g), P content similar to common GLVs, better bioavailability of minerals and higher dietary fiber content than coventional GLVs	Underutilized GLV	(Gupta et al., 2005)
Portulaca oleracea	Purslane	One of the richest plant source of omega-3 fatty acids. Contains α-linolenic acid, palmitoleic, palmitic, linoleic, oleic and stearic acids, carotenoids, α- and β-carotene, lutein and zeaxanthin. Tocopherols, vitamin C and vitamers of complex-B, oxalic acid and minerals, alkaloids, mucilages and pectins, flavonoids, phenolic acids, lignins, stilbenes, terpenoids, saponins, tannins, chlorophyll, bergapten and robustin	Salt-resistant, annual widespread Mediterranean GLV, used in salads	(Petropoulos et al., 2018; Eşiyok et al., 2018)
Raphanus raphanistrum	Wild radish leaves	21.2 mg/100 g FW of P-coumaric acid	Erect herb, with trichomes distributed along the plant. Native from Europe, mostly found in the southern Europe and all over the Mediterranean region in temperate and subtropical climate regions. Edible leaves, young stems, flowers, roots and seeds. Can be eaten either raw in salads or cooked in soups and as boiled vegetable. Slightly spicy taste	(Mazzucotelli et al., 2018; Iyda et al., 2019)
Rumex acetosa	Sorrel	Ascorbic acid (124 mg/100 g) and oxalic acid (0.3%), vitamin A and B. Laxative, diuretic, antiscorbutic and refrigerant	Underutilized GLV with long and rhizomatous roots. The leaves constitute a basal rosette.	(Eşiyok et al., 2018; Ceccanti et al., 2020)
Salicornia europaea	Glasswort	Contains flavonoids and coumarins and high contents of branched chain amino acids	Annual herbaceous wild halophyte (salt tolerant) with medicinal value	(Wang et al., 2021)
Salicornia herbacea	Grasswort	Caffeoylated quinic acid derivatives (CQAs) such as 3-O-Caffeoyl-5-O-dihydrocaffeoyl quinic acid, 4,5-di-O-dihydrocaffeoyl quinic acid and 3,5-di-O-caffeoyl quinic acid. Flavonol glucosides, saponins, linoleic and linolenic acids, phenylpropanoic acids. The flavonols content depends on the growth stage with higher contents being detected at maturity stage	Wild species. Salt-tolerant (Mediterranean halophyte)	(Petropoulos et al., 2018)
Salsola soda, Liscari sativa	Riscolo, Roscano, Barella, Agretti, Almyra	Flavonoids, minerals, acetophenones, coumarins, sterols, tetrahydroisoquinoline alkaloids, such as salsoline, salsolidine, N-methylisosalsoline and carnegine	Wild Mediterranean halophyte with phytopharmacological effects	(Petropoulos et al., 2018)
Sanguisorba minor	Salad burnet	High total phenolic, flavonoid and carotenoid content	Wild species. Grows in dry and moist environments. Its taproot has a high water-storing capacity, allowing resistance to drought. Forms a basal rosette	(Ceccanti et al., 2020)

(*continued on next page*)

Table 1 (*continued*)

Scientific name	Common name	Nutritional value	Characteristics	Reference
Scolymus hispanicus	Golden thistle	Abundance of chlorogenic acid and lower amounts of 3,5- and 1,5-dicaffeoylquinic acids. Also contains glucose, fructose, sucrose and inulin	Prickly perennial herbaceous plant, native to Southern Europe, Mediterranean and Western Asia. Grows in mild climates	(Sergio et al., 2023)
Sonchus arvensis	Sow thistle	Contains N, P, K, vitamin C, chlorophyll, carotenes, anthocyanins, quercetin, kaempferol, rutin, myricetin, luteolin and apigenin	Underutilized GLV. Simultaneous harvesting of lower and upper leaves is recommended to obtain high production and quality	(Raisawati et al., 2023)
Sonchus oleraceus	Sow thistle	Rich in minerals, vitamin C, carotenoids, omega-3 fatty acids, flavonoids, flavonols, and phenols, with anti-fungal and anti-toxigenic properties	Wild, salt-tolerant GLV, widely distributed in the Mediterranean and used in salads, pies and soups	(Guil-Guerrero et al., 1998; Gkotzamani et al., 2024)
Spinacia oleracea	Spinach	High fiber content and exceptionally high contents of vitamin A and K1 (phylloquinone). Half-cup of boiled spinach provides 573 mcg of vitamin A, which is 229% of the daily value. Contains free forms of water soluble vitamins (vitamins B1, B2, B3, B5, B6, B9 and C), fat-soluble vitamins (pro-vitamin A and vitamin E), p-coumaric acid (9.37 mg/100 g FW), Ca (1036 mg/100 g), Mg (827 mg/100 g), Fe (28.4 mg/100 g) and Na (827 mg/100 g), alpha−linolenic acid (1.7 mg/g). 370 mg/100 g of omega−3 fatty acids. Provides all the essential amino acids	Important GLV, grown worldwide both in temperate regions and in the cooler parts of the tropic regions	(Ma et al., 2016; Mazzucotelli et al., 2018)
Taraxacum erythropodium	Dandelion	Contains chlorogenic acid and caffeic acid	Strong resistance to environmental adversities. Can be cultivated on saline land for vegetable production	(Wu et al., 2019)
Taraxacum officinale	Dandelion	Low nitrate content	Perennial underutilized GLV. Very popular spring salad in the Balkans. Strong resistance to environmental adversities	(Gorenjak et al., 2012; Baidoo et al., 2014)
Trianthema portulacastrum	Horse purslane	Protein 2.5 g/100 g, P and K content similar to common GLVs, Mn 0.43 mg/100 g. Better bioavailability of minerals than coventional GLVs	Easily available and tolerant to adverse conditions	(Gupta et al., 2005; Ara, 2015)
Trigonella foenum-graecum	Fenugreek	Good source of soluble dietary fiber	Nitrogen-fixing (legume). Adapted to variable climatic conditions and growing environments. Low water needs. Could be incorporated into short term rotations. Fast germination time (3–10 days). Slower growth under cooler and wetter conditions	(Mehrafarin et al., 2011)
Urtica dioica	Stinging nettle	Flavonoids, tannins, scopoletin, fatty acids, phenolic compounds, glycoside, and sterols. Demonstrates anti-nociceptive, anti-inflammatory, anti-diabetic, diuretic, digestive, and immunostimulatory properties	Perennial herbaceous plant with spiny leaves. The sensitive highest shoots and top green leaves are harvested for consumption. Also used as a fertilizer in organic farming for horticultural crops	(Bhusal et al., 2022)
Urtica urens	Annual nettle	Flavonoids, tannins, scopoletin, fatty acids, phenolic compounds, glycoside, and sterols. Demonstrates anti-nociceptive, anti-inflammatory, anti-diabetic, diuretic, digestive, and immunostimulatory properties	Annual monoecious species. Spreads vegetatively by branching rhizomes and by seed. Found in nutrient-rich soils	
Valerianella locusta	Mache, Corn salad, Lamb's lettuce	Important source of physiologically-active components such as phenolics, carotenoids, sterols and fatty acids that can be utilized for colorectal cancer prevention	Used for fresh-cut salads and salad mixes. Native to Europe and the Mediterranean. Annual, tolerant to low temperatures	(Sagwansupyskorn, 1993; Ramos-Bueno et al., 2016)

reported eating at least one portion daily, though consumption varied significantly among member states; nearly one-fifth consumed vegetables only one to three times a week, while 96.4% consumed them at least weekly, leaving a small minority abstaining altogether (Eurostat, 2024).

Despite some improvements, global production and consumption of fruits and vegetables remain below FAO and WHO recommendations for optimal health, contributing to approximately 4 million premature deaths annually (FAO, 2023). GLVs pose challenges in accurate dietary estimation and consumption assessment, potentially indicating lower actual consumption than reported levels, especially outside specific regions where they are more popular.

In Europe, particularly in Mediterranean countries like Italy, Spain, Greece, and Croatia, GLVs are regularly consumed as main ingredients or accompaniments. The Mediterranean diet, known for its emphasis on fresh, whole foods, has long been linked to various health benefits (Kaufman-Shriqui et al., 2022), with GLVs being a key component that underscores the diet's focus on plant-based nutrition. GLVs are integral to the diets of various African communities, providing essential nutrients and contributing to food security across socio-cultural and economic backgrounds, as seen in examples such as collard greens in Ethiopia and Sukuma wiki in Kenya. Initiatives aimed at promoting the cultivation and consumption of GLVs, like amaranth, African spinach and waterleaf in Nigeria and amarantus, spider plant and cassava leaves in Tanzania, highlight their nutritional value and resilience, reinforcing their significance in improving dietary diversity and nutrition security (Mabhaudhi et al., 2018).

Blue zones are regions worldwide where people live exceptionally long, healthy lives compared to global averages. These areas include Okinawa in Japan, Ikaria in Greece, the mountainous Sardinian region in Italy, and the Nicoya Peninsula in Costa Rica. Dietary habits are a significant factor influencing longevity, with considerable interest in specific foods believed to enhance health and maintain functional capacity as individuals age (Yeung et al., 2021).

In blue zones, diets are characterized by regular consumption of GLVs and other plant-based foods. Ikaria, an island rich in biodiversity at the crossroads of Europe, Asia, and Africa, features a diet rich in plant foods such as lettuce, green onions, chickpeas, lentils, and fresh fruits (Legrand et al., 2019). Similarly, in Sardinia, a popular dish is minestrone soup, abundant with nutrient-dense vegetables like onions, fennel, carrots, and a variety of legumes such as beans, broad beans, and peas, often accompanied by hearty potatoes (Fastame MC, 2022). Over time, Sardinians have increasingly adopted a diet rich in vegetables and fruits, aligning closely with the renowned Mediterranean dietary pattern (Pes et al., 2022).

In summary, in blue zones, GLVs are regularly consumed, either as raw salads, cooked dishes, or incorporated into traditional recipes. Regular consumption of fresh vegetables is believed to contribute to the lower rates of chronic diseases and higher life expectancies observed in these regions (Pes et al., 2022). As such, the emphasis on vegetables in the diets of blue zone populations highlights their importance as a key component of a healthy and longevity-promoting diet. Notably these dietary principles can be implemented worldwide, regardless of geographical location or cultural background. By emphasizing the consumption of nutrient-rich whole foods, including GLVs, and minimizing the intake of processed and unhealthy foods, individuals can adopt a lifestyle that supports optimal health and well-being (Pieroni et al., 2023). As suggested by Murphy and Parletta (2018), the adoption of measures such as promoting home cooking, implementing community-based interventions, and enacting policy reforms stands as a crucial initiative in the adaptation and application of the principles underpinning the blue zone diet. The same approach could be applied to promote the consumption of GLVs, offering significant potential for improving health outcomes and promoting longevity among diverse global populations.

4. Nutritional and health benefits of green leafy vegetables and their small counterparts

GLVs are rich in nutrients and bioactive compounds known for their health benefits, including antioxidants, anti-inflammatory agents, and anticancer properties, which help prevent non-communicable diseases. Dark GLVs are linked to lower risks of type II diabetes, cardiovascular diseases, various cancers, and depression (Takata et al., 2013). They are significant sources of bioactive secondary metabolites, such as polyphenols, which enhance antioxidant capacity by scavenging free radicals and inducing antioxidant enzymes (Sivakumar et al., 2018). Consumption of leafy greens, such as spinach, enhances cellular antioxidant activity, elevates blood antioxidant status, and reduces susceptibility to associated diseases (Neugart et al., 2017). These benefits are attributed to the presence of antioxidant vitamins like ascorbic acid and polyphenols, which are abundant in these vegetables (Sivakumar et al., 2018). Additionally, leafy greens have been shown to increase the total antioxidant capacity of blood plasma (Hollman et al., 2011), potentially by stimulating endogenous antioxidant systems, inducing antioxidant enzymes, and preventing lipid oxidation in pre-consumption food, thereby reducing overall prooxidant intake (Vance et al., 2016).

Phenolics play a pivotal role in enhancing the antioxidant capacity of GLVs, offering protection against diseases associated with oxidative stress, including cancer, cardiovascular issues, and diabetes (Blekkenhorst et al., 2018). Their abundance in these vegetables underscores their potential to promote health through diverse antioxidant properties (Moyo et al., 2021). Various classes of polyphenols, such as flavonoids and phenolic acids like ferulic acid, also exhibit anti-inflammatory properties (Oluwole et al., 2021).

Furthermore, GLVs are recognized as sources of anticancer compounds. Phenolic compounds found in these vegetables primarily exert their anticarcinogenic effects by inducing cell cycle arrest, inhibiting oncogenic signalling pathways involved in cell proliferation, angiogenesis, and apoptosis regulation (Anantharaju et al., 2016). These molecules also modulate reactive oxygen species levels, promote the expression of tumour suppressor proteins, and support the differentiation of affected cells into normal cells (Basli et al., 2017).

Lutein, a hydrophobic carotenoid found in GLVs like kale, spinach, and broccoli, ranges from 2 to 15 mg per 100 g (Mitra et al., 2021). It offers various health benefits, including support for neurological health, vision, and cardiovascular well-being (Mitra et al., 2021). Research suggests lutein may enhance cognitive function and protect against age-related macular degeneration (Woo et al., 2013). Additionally, lutein demonstrates antimicrobial properties and has potential roles in managing conditions like malaria and skin irritation (Mitra et al., 2021). Achieving recommended lutein intake levels (6–12 mg) through diet can help reduce cognitive decline and support overall health (Woo et al., 2013). Consuming GLVs offers numerous benefits in combating the aging process. Oxidative stress and free radical damage contribute to age-related cellular and tissue changes, making antioxidant-rich foods like GLVs crucial for mitigating these effects (Rizvi et al., 2023). GLVs, such as lettuce, are particularly rich in polyphenols, which can protect the brain and nervous system from aging-related damage by crossing the blood-brain barrier. Additionally, GLVs are abundant sources of vitamins A and C, which promote skin health by supporting collagen development, aiding in anti-aging skin treatments, and enhancing wound healing.

The vitamin K content in GLVs, including varieties like romaine lettuce, is essential for bone health, increasing bone density and reducing the risk of osteoporosis (Chaudhary, 2015). Moreover, GLVs contain a range of minerals and vitamins, including iron, magnesium, potassium, and vitamin B, which support metabolic processes and provide the necessary energy for daily activities (Xiao et al., 2012).

Nitrate in GLVs is crucial for cardiovascular health, as it boosts nitric oxide levels, essential for vascular balance. Nitric oxide facilitates blood vessel relaxation and inhibits platelet adhesion, potentially slowing atherosclerosis progression. Regular GLV consumption may help prevent or mitigate cardiovascular diseases (Zurbau et al., 2020). Studies show that nitrate-rich GLVs like spinach, arugula, and beetroot can effectively lower blood pressure (Jonvik et al., 2016). For instance, Liu et al. (2013) found that a single meal with nitrate-rich spinach improved blood pressure and arterial stiffness in healthy adults. Increasing GLV consumption could enhance dietary nitrate intake, benefiting cardiovascular health (Van der Avoort et al., 2018).

Epidemiological studies reveal the cardioprotective effects of GLVs, indicating inverse associations between their intake and conditions like coronary heart disease and stroke mortality (Ojagbemi et al., 2021). Blekkenhorst et al. (2018) highlighted this inverse relationship, emphasizing the role of GLVs in reducing cardiovascular disease risk.

Incorporating GLVs into diets is essential for health promotion and chronic disease prevention (Zurbau et al., 2020). Just one daily serving of GLVs can reduce cardiovascular disease incidence, including coronary artery disease, stroke, and coronary heart disease mortality, by 12%–18% (Zurbau et al., 2020). GLVs are also vital sources of essential minerals, such as sodium and potassium for metabolic functions, calcium for bone health, and phosphorus, magnesium, iron, and zinc for overall well-being (Santos et al., 2014). Furthermore, GLVs provide essential vitamins like A, C, and B1, crucial for human health. Research from Tanzania indicates that increased GLV consumption can reduce anemia and micronutrient deficiencies, especially in resource-limited communities (Stuetz et al., 2019).

GLVs are highly nutritious but contain anti-nutritional factors such as cyanogenic glycosides, phytates, oxalates, tannins, and nitrates (Moyo et al., 2021). These compounds can impair protein digestibility and hinder the absorption of essential minerals like iron, copper, calcium, and zinc by forming insoluble complexes (Natesh et al., 2017). Despite these drawbacks, GLVs are generally safe for consumption, exhibiting minimal cytotoxic activity both raw and cooked (Moyo et al., 2021). This underscores the importance of balancing their nutritional benefits with an awareness of potential anti-nutritional effects.

Microgreens represent a novel category of edible plants renowned for their ability to address nutritional deficiencies and enhance health significantly. They include vitamins such as ascorbic acid, tocopherol (vitamin E), phylloquinone (vitamin K), β-carotene, violaxanthin, and lutein (Xiao et al., 2012). Rich in minerals and bioactive compounds, microgreens also exhibit high levels of phytochemicals like phenolic antioxidants, anthocyanins, and glucosinolates. For instance, lettuce microgreens are notably richer in calcium, magnesium, iron, manganese, zinc, and molybdenum compared to their mature counterparts (Rizvi et al., 2023). Microgreens offer enhanced bioavailability and bioaccessibility of nutrients such as iron, potassium, magnesium, and zinc (Sirtautas et al., 2012). They surpass mature plants in nutritional content, containing higher levels of minerals like fluoride, selenium, calcium, and phosphorus, as well as vitamins such as folic acid, vitamin C, and omega-3 fatty acids (Singh et al., 2020).

Beyond nutrition, microgreens are noted for their health-promoting properties, including anti-cancer, antimicrobial, antioxidant, anti-inflammatory, and anti-diabetic effects. They have shown potential in regulating hormone-dependent cancers like breast and prostate cancer and protecting against cardiovascular diseases (Johnson et al., 2021).

Their abundance of flavonoids also supports gut health by potentially regulating microbiota (Ghoora et al., 2020). Finally, green and microgreen leafy vegetables are not only rich in essential nutrients such as phytochemicals, bioactive components, minerals, and vitamins (Moyo et al., 2021; Sarkar et al., 2023) but they also possess various medicinal properties which include healing capabilities for conditions like peptic ulcers, jaundice, toothache, and intestinal problems (Moyo et al., 2021).

Despite the wealth of documented health benefits linked to GLVs, specific varieties continue to be underutilized, undervalued, and overlooked (Knez et al., 2023). Furthermore, insufficient consumption of GLVs deprives individuals of the numerous health benefits offered by these nutritious foods.

Despite their recognized nutritional value, many people fail to incorporate an adequate amount of GLVs into their diets, potentially missing out on essential vitamins, minerals, antioxidants, and phytochemicals crucial for maintaining optimal health. This highlights the importance of advocating for increased consumption of GLVs to improve health outcomes and prevent diet-related diseases. Encouraging individuals to incorporate a wider variety of leafy greens into their daily diet can enhance overall nutritional intake and contribute to better health outcomes over time.

5. Socio-economic and cultural aspects of green leafy vegetable consumption

GLVs often struggle in mainstream markets and urban consumer preferences due to their association with low-status food and rural lifestyles (Ngidi et al., 2023). This perception, coupled with limited awareness of their nutritional benefits, contributes to their declining popularity (Ngidi et al., 2023). Factors such as inadequate post-harvest handling, ineffective marketing strategies, and insufficient culinary experience worsen this trend (Gido et al., 2017). Additionally, the bitter taste of some varieties discourages consumption (Gido et al., 2017). Historical factors, including colonization and globalization, have reinforced the perception of traditional crops as 'poverty foods' (Sahoo et al., 2021).

Meanwhile, 'modern' foods were introduced and considered more desirable, leading to a decline in dietary diversity and the exclusion of underutilized indigenous and traditional crops from dominant food systems (Sahoo et al., 2021)). As a result, certain green leafy varieties have been downgraded to alternative and informal food channels.

The integration of leafy plants into the Mediterranean diet dates to the Neolithic Age, where they served as both sustenance and medicinal resources (Leonti, 2012). These plants play a critical role in reflecting local culture and economic activity within Mediterranean diets, commonly found in farmers' markets and taverna menus. However, familiarity with these plants is predominantly among older community members, with younger generations lacking both knowledge and culinary skills to utilize them effectively (Pieroni et al., 2023).

Despite the numerous advantages of Mediterranean diets in terms of environmental sustainability, human health, economic viability, and social cohesion, adherence to them remains suboptimal, even in Mediterranean-bordering countries (Pieroni et al., 2023). Cultural preferences and culinary traditions often elevate alternative food types over GLVs, contributing to their diminished consumption rates. Additionally, socioeconomic factors play a significant role, as marginalized communities and individuals facing financial constraints may struggle to access fresh and affordable GLVs, opting instead for cheaper but less nutritious alternatives (Monterrosa et al., 2020). Furthermore, marketing and advertising strategies tend to promote processed and fast foods, which may further reduce the appeal of GLVs in dietary choices (Chen and Antonelli, 2020). These factors collectively influence dietary patterns, impacting the consumption of GLVs despite their nutritional benefits and historical significance within Mediterranean diets.

Recent reviews highlight that current Food-Based Dietary Guidelines often diverge from the principles for Sustainable Healthy Diets proposed by FAO and WHO (Klapp et al., 2022). This discrepancy underscores the necessity of updating national dietary guidelines to reflect the latest evidence on healthy eating, including promoting increased consumption of GLVs. Such dietary adjustments could not only improve health outcomes but also contribute to reducing environmental impacts, aligning with broader sustainability criteria (Springmann et al., 2018).

Additionally, raising awareness about the accessibility and benefits of locally available, cost-effective foods such as traditional GLVs is crucial (D'Innocenzo et al., 2019). Emphasizing their nutritional value and cultural significance can encourage their incorporation into diets without compromising taste and enjoyment. This knowledge transfer is essential for younger generations and can be facilitated through engaging tools involving local stakeholders and social entrepreneurs (Pieroni et al., 2023).

GLVs are crucial for nutrition and economic development across various regions, including North America, Africa, and the Middle East. In North America, urban farming and initiatives like the Farmers' Market Promotion Program have increased the availability of GLVs, enhancing income and food security. In Africa, crops like amaranth and cowpea leaves provide essential nutrients and income for farmers, with programs such as HarvestPlus promoting biofortification and market access for smallholders. In the Middle East, traditional GLVs like molokhia and purslane are integral to diets and livelihoods, supported by governmental initiatives aimed at improving food security (Kumar et al., 2020). The cultivation of GLVs also supports local economies; for example, in Kenya, the Kenya Agricultural Value Chain Enterprises Program has improved market access for smallholder farmers, leading to increased incomes and employment opportunities in the agricultural sector (Mabhaudhi et al., 2018).

The production of GLVs can significantly impacts income, employment, efficiency, trade, and productivity. By diversifying GLVs, farmers, particularly smallholders, can boost their income through increased market demand and access to niche markets, while also securing their income against unexpected weather events caused by climate change. Additionally, intercropping and rotation systems can enhance soil fertility and overall production. GLV cultivation generates substantial employment opportunities, particularly for women, while promoting innovative agricultural practices that optimize resource use and improve productivity. Furthermore, increased GLV production facilitates participation in local and international trade, enhancing economic growth and food security.

Profitability can serve as a significant incentive for cultivating GLVs similar to commercial crops like rice and wheat, highlighting their potential for increased income and improved dietary diversity. Profitability will further increase as consumers recognize the value of these products in their diets and citizens become more aware of the environmental benefits, thereby contributing significantly to this effort. By diversifying crop production with GLVs, farmers can reduce reliance on staple crops, tap into growing urban markets, and achieve quicker returns on investment (Lino et al., 2022). Additionally, GLVs can address nutritional deficiencies in local communities and promote sustainable farming practices, as many are resilient to adverse environmental conditions and require fewer chemical inputs.

GLVs can play a pivotal role in educational initiatives and school lunch programs aimed at increasing consumption of fresh, nutritious, locally produced salads (Tyson et al., 2016). A holistic approach to healthy eating, including traditional and locally produced GLVs, highlights their nutrient richness and health benefits, potentially reversing declining consumption trends (D'Innocenzo et al., 2019). Educational efforts targeting youth in Mediterranean regions can promote the consumption of wild greens by teaching gathering, cleaning, cooking, and serving techniques (Hartmann et al., 2013). Lastly, emphasizing the ecological significance of GLVs can further encourage their consumption, given their role in environmental sustainability and their nutritional benefits for overall health (Springmann et al., 2018). Addressing the societal and cultural aspects of low consumption of GLVs requires multifaceted approaches. These may include educational campaigns to raise awareness about their nutritional benefits, initiatives to improve accessibility and affordability, and efforts to challenge stereotypes and promote cultural acceptance of these vegetables as integral components of a healthy diet. Incorporating culinary experiences that showcase the diverse ways in which leafy greens can be prepared and enjoyed can further enhance their appeal and encourage their broader implementation in dietary practices.

6. Enhancing food security, promoting agrobiodiversity, and addressing the food crisis with increased green leafy vegetable consumption

By the mid-1900s, the global population reached approximately 2.5 billion, with many industrialized nations achieving food security (Pingali, 2012). Today, surpassing 7.8 billion, global food challenges persist, including access, availability, and distribution issues leading to food insecurity and malnutrition (Ratnayake et al., 2023). The Green Revolution introduced high-yielding cereal varieties like maize, wheat, and rice, shaping an agro-industrial food regime (Kerr, 2012). Despite its successes, the Green Revolution brought environmental and nutritional challenges (Dudley and Alexander, 2017). The current global food system struggles to meet nutritional needs, highlighted by the Sustainable Development Agenda and a recent WHO report indicating no region is on track to meet dietary and environmental goals (FAO, IFAD, UNICEF, WFP, WHO, 2023). This system, reliant on a limited plant diversity, faces vulnerabilities to economic and climatic disruptions (Gordon et al., 2017).

The agro-industrial food system has often overlooked traditional plant varieties, including GLVs, which were once vital components of local diets and ecosystems. These varieties have been supplanted by high-yielding, input-intensive crops, leading to the loss of biodiversity and undermining local food systems (Gordon et al., 2017). This shift compromises the nutritional quality of diets, posing risks to human health and well-being. While staple cereal crops provide sufficient energy, their consumption in isolation often results in inadequate nutrition due to the absence of essential nutrients found in other crops (Alders, R. and Kock, R., 2017). Over time, many varieties of GLVs have been neglected and forgotten, further exacerbating these issues.

Hence, advocating for neglected GLV varieties is crucial. Resilient to climate change and beneficial for resource-poor farmers, GLVs offer alternatives amid shifting weather patterns. They also enhance biodiversity through a diverse array of cultivated and underexploited species. Wild GLV species are particularly valuable for their potential in discovering climate resilience and enhancing genetic diversity, while also providing essential ecosystem services (Knez et al., 2023'). Table 1 lists potential underutilized varieties for cultivation.

GLVs offer significant nutritional benefits, contributing to dietary diversification, local food security, and health (Hunter et al., 2019). Cultivating underutilized GLVs preserves agrobiodiversity, promoting sustainable development and improving nutrition and health outcomes essential for productivity, livelihoods, and well-being (Knez et al., 2023). This diversification supports the UN Sustainable Development Goals, particularly in combating malnutrition and achieving food security (Feliciano, 2019). Defined by FAO and WHO (2019), 'Sustainable Healthy Diets' promote overall health, minimize environmental impact, and are accessible, affordable, safe, equitable, and culturally acceptable. These diets integrate food-based approaches with nutrient recommendations to address health, environmental, social/cultural, and economic sustainability, crucial for transforming global food systems (FAO and WHO, 2019). Incorporating indigenous and traditional greens into the food system holds promise for enhancing dietary diversity, improving nutritional status, and reducing global food insecurity (Ratnayake et al., 2023).

In summary, GLVs are rich in essential nutrients but often go unrecognized due to perceptions of low economic value, limited awareness of their nutritional benefits, cultural factors, insufficient infrastructure, and generational knowledge gaps.

Despite these challenges, integrating GLVs into food systems could effectively address global malnutrition, enhance dietary diversity, improve nutritional status, and bolster food security. Advocating for increased cultivation and consumption of both commonly consumed and underutilized green leafy crops can play a pivotal role in advancing sustainable development goals.

7. Strengthening biodiversity, climate resilience, and environmental sustainability through the promotion and cultivation of green leafy vegetables

Climate change presents a formidable challenge, marked by an increase in extreme weather events, particularly prolonged and more frequent droughts (D'oira et al., 2022). Concurrently, soil degradation exacerbates these issues, significantly impacting both the quantity and quality of food production (D'Oria et al., 2022; Park et al., 2023).

These climatic shifts contribute to various agricultural challenges, including water scarcity, salinity issues, and adverse temperature effects on plant growth. Temperature plays a crucial role in leafy vegetable production, affecting germination, growth, yield, quality, and shelf-life (Ray et al., 2021). It also influences seed production, dormancy, viability, longevity, and the prevalence of pests and diseases (Ray et al., 2021).

Modern agricultural practices, originally aimed at boosting food production, now face the threat of climate-induced productivity declines, potentially leading to food shortages amid a growing global population. Current sustainable resource management strategies may not fully meet the United Nations Sustainable Development Goals, particularly in poverty reduction, hunger eradication, and global health improvement (Singh et al., 2019). Moreover, the focus on a limited range of staple crops and vegetables in agricultural investments overlooks the potential of numerous other nutrient-rich greens (Schreinemachers et al., 2018).

To meet rising food demands sustainably, exploring nutritionally rich, low-resource-intensive, and climate-resilient underutilized local crops is crucial, especially in developing nations. Integrated indigenous and local knowledge systems offer valuable insights for sustainable ecosystem management, aligning with efforts to reduce ecological footprints (Singh et al., 2019). Singh et al. (2019) advocate a four-step approach focusing on underutilized leafy vegetables, emphasizing investigation, refinement, development, and promotion to enhance food security and provide pharmacological benefits. Conventional agriculture contributes to environmental degradation through pollution and resource depletion (Carlisle et al., 2019). Agroecology advocates prioritize biodiversity and reduce external inputs (Tüzel and Öztekin, 2018). GLVs are key in addressing climate change and food security due to their adaptability, high yields, and minimal resource needs. GLVs improve soil structure, reduce erosion, and enhance agricultural resilience (Norris and Congreves, 2018).

Intercropping systems enhance soil health and ecosystem dynamics by promoting synergistic plant interactions (Layek et al., 2018). They improve soil structure, nutrient diversity, and stability, reducing the need for intensive management and external inputs (Andersen et al., 2007). Intercropping also supports biodiversity, pest control, and soil fertility naturally, often yielding higher quality outputs and economic returns compared to monoculture (Sekine et al., 2021). For GLVs, such systems can optimize nitrogen use and prevent soil nitrogen leaching, enhancing nutrient efficiency (Ding et al., 2021). Similarly, GLVs play a crucial role in climate change mitigation by sequestering carbon dioxide due to their high-water content and rapid growth (Ding et al., 2021). They also aid in managing excess water, contributing to flood mitigation efforts.

Likewise, crop rotation alternates crops in a field to manage pests, improve soil fertility, and control weeds (Iheshiulo et al., 2023). GLVs, with their short growth cycle and ability to be grown multiple times annually, are ideal for crop rotations. This practice helps break pest and disease cycles, reduces pesticide use, enriches soil with organic matter, and promotes sustainable soil management (Norris and Congreves, 2018).

GLVs offer advantages due to their independence from pollination, unlike fruit-bearing vegetables reliant on bees. This reduces dependency on external pollinators and mitigates risks from fluctuating bee populations. Self-pollinated GLV varieties ensure uniformity and stability in traits, warranting predictable yields and quality (Pandita et al., 2023).

GLVs, including underutilized varieties like Purslane species, thrive in wet soils, propagate easily through seeds or vegetative means, and exhibit resilience to various soils and drought conditions (Srivastava et al., 2023). With robust growth potential and efficient nutrient absorption, GLVs contribute to sustainable agriculture, enhancing food security and farming system resilience.

GLVs are well-suited for diverse environmental conditions, with varying heat tolerance and adaptability to temperature, salinity, and pH fluctuations (Srivastava et al., 2023). They offer high nutritional, medicinal, and industrial value, making them beneficial for both industrial development and addressing nutritional needs. With minimal agronomic requirements and ease of cultivation, GLVs are ideal for resource-poor farmers in developing regions, promoting sustainable agriculture and conserving neglected crops globally (Srivastava et al., 2023).

Intensified agricultural practices in conventional food systems contribute to environmental degradation through ammonia emissions and excessive agrochemical use (Alsaffar, 2016). Advocating for regulated agrochemical use and promoting underutilized indigenous GLVs can mitigate these impacts while enhancing nutritional quality and environmental sustainability (Ngigi et al., 2023). Shifting towards more plant-based food systems, which include nutrient-rich traditional crops like GLVs, can improve overall nutrition and health outcomes (Ngigi et al., 2023). To reduce environmental impacts, strategies like reducing animal-sourced foods in diets can significantly cut greenhouse gas emissions (Boe, 2023). Transitioning to plant-based diets has been shown to potentially reduce food-related emissions by 29%–70% (Carey et al., 2023). Increasing agrobiodiversity, including resilient crops such as GLVs, is crucial for enhancing food and nutrition security amidst challenges like droughts and soil variability (Park et al., 2023).

Microgreens, often hailed as a 'wonder food,' show promise in combating energy and protein malnutrition in regions with prevalent deficiencies (Rizvi et al., 2023). They represent a sustainable agricultural opportunity suitable for modern farming practices, offering potential for higher income in shorter growing periods. Cultivating microgreens is cost-effective, requiring minimal tools and materials. Plastic seed trays with good drainage or simple containers and pots suffice for domestic cultivation. Sanitizing seeds before planting eliminates potential pathogenic contamination (Di Gioia and Santamaria, 2015) and adjusting seed density optimizes production. Microgreens typically have a shelf life of about 10 days, but certain varieties can be stored longer at lower temperatures with modified CO_2 and O_2 levels (Rizvi et al., 2023).

Continued research is vital to ensure widespread acceptance of microgreens in global diets, integrating them throughout the food chain. Promoting microgreens cultivation and consumption offers a strategic approach to bolstering food security and nutritional well-being while addressing climate change impacts.

GLVs offer a significant advantage with their short cultivation cycle and ability to thrive in small areas, making them ideal for producing microgreens and baby leafy greens valued for rapid growth and high nutritional content (Rizvi et al., 2023). Their compact leaf area often eliminates the need for plant support, enabling mechanical harvesting and suitability for modern sustainable systems like hydroponics and vertical farming. This makes GLVs viable in urban settings and other spaces with limited growing conditions such as balconies, city gardens, and rooftops, benefiting microclimate regulation and enhancing urban food system resilience (Kandel and Frantzeskaki, 2023).Optimizing the food supply chain is critical today to improve efficiency from harvest to market and provide consumers with a wider range of nutritious foods. Effective postharvest handling of horticultural products, including GLVs, is crucial for reducing food waste and ensuring food safety (Tort et al., 2022). However, GLVs are highly perishable due to their high respiration rates and water loss, typically offering a shelf life of a few days to two to three weeks even under optimal conditions. The quality of GLVs is influenced by factors such as appearance, colour, and flavour, with common postharvest issues including yellowing and wilting (Saltveit, 1999). Maintaining a cold chain is essential for effective postharvest handling to minimize tissue transpiration in GLVs. Technology-driven approaches in GLV cultivation can yield profitability within a short timeframe (Schreinemachers et al., 2018). Training for farmers and research on modern technologies are crucial for maximizing the marketable life of GLVs, alongside exploring new distribution channels like online grocery platforms and optimizing market handling techniques.

Adequate processing and post-harvest technologies are essential for improving the value and accessibility of leafy vegetables. Methods like drying, freezing, and pickling can extend shelf life and enhance marketability, while value addition strategies-such as ready-to-eat products and incorporating leafy greens into snacks-create new revenue opportunities. Investments in cold chain logistics, storage facilities, and modified atmosphere packaging help reduce waste and maintain quality. Additionally, initiatives that improve market access, provide farmer training, and foster cooperatives can enhance distribution efficiency and empower producers. Maintaining a cold chain is vital for minimizing transpiration in green leafy vegetables, and leveraging technology and modern distribution channels is key to maximizing profitability and marketable life. Prioritizing the cultivation and consumption of GLVs offers environmental benefits, especially when combined with biodiversity promotion, intercropping, and crop rotations. Diversifying GLV cultivation enhances ecosystem resilience against pests and diseases while providing rich sources of essential nutrients that support overall health and reduce chronic disease risks. GLVs' adaptability to environmental stressors ensures resilience in adverse conditions, promoting dietary diversity and sustainable food production systems. Emphasizing GLVs in agrobiodiversity initiatives is essential for addressing nutritional deficiencies, enhancing food security, and fostering resilient agricultural systems, thereby benefiting human health and environmental sustainability.

8. Conclusions with recommendations for further research and actions

GLVs are essential for promoting health and addressing nutritional deficiencies due to their culinary versatility, high nutritional value, and health benefits, including antioxidant, anticancer, antidiabetic, and anti-inflammatory properties. To enhance GLV consumption, efforts must address food supply disparities through regulatory measures, improved access, and public health campaigns. Highlighting the health benefits and economic viability of dietary patterns rich in GLVs, such as the Mediterranean diet, is also crucial.

Collaboration among government agencies, policymakers, the food industry, retailers, and health professionals are vital to promote healthy dietary patterns that include GLVs. Utilizing undomesticated and wild crops aligns with United Nations Sustainable Development Goals and requires targeted improvement, domestication, and mass cultivation programs. Supporting local farmers, sustainable farming practices, and market development can ensure the long-term availability of diverse GLV varieties.

Integrating underutilized indigenous and traditional varieties into the food system can combat malnutrition, biodiversity loss, and environmental degradation. Adapting GLV production to climate change involves studying climate impacts, developing resilient supply chains, and implementing sustainable postharvest practices, contributing to dietary improvements and broader societal goals like employment and environmental sustainability.

Technological advancements in GLV production, including precision agriculture, innovative cultivation methods, and improved postharvest handling, can enhance productivity and efficiency. Sustainable agricultural techniques, such as climate-smart practices and sustainable intensification, are necessary to mitigate environmental impacts and improve ecosystem services.

Promoting research initiatives, advocating for increased GLV cultivation and consumption, and incorporating a broader range of GLVs into sustainable agricultural frameworks are essential for achieving health, nutrition, and environmental sustainability. By addressing these challenges and leveraging the potential of GLVs, we can establish resilient food systems that support human health and preserve environmental integrity.

CRediT authorship contribution statement

Marija Knez: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Konstadinos Mattas:** Validation, Supervision, Funding acquisition, Conceptualization. **Mirjana Gurinovic:** Writing – review & editing, Validation, Supervision. **Anna Gkotzamani:** Writing – review & editing, Investigation. **Athanasios Koukounaras:** Writing – original draft, Validation, Supervision, Investigation, Conceptualization.

Declaration of competing interest

All authors declare that they have no conflicts of interest.

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Data availability

No data was used for the research described in the article.

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