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REVIEW

Microgreens in modern gastronomy: balancing nutritional value and microbiological risks

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Summary

The integration of microgreens into modern gastronomy reflects a shift from decorative garnishes towards ingredients valued for nutritional density and sensory appeal. Marketed as "superfoods" and consumed raw as ready-to-eat products, their adoption has generated a critical paradox: while perceived as inherently safe, microgreens exhibit biological characteristics that predispose them to latent microbiological risks. This review examines the gap between health benefits and safety challenges in microgreen production and consumption. Analysis of the supply chain, from seed to fork, emphasises seed contamination, systemic pathogen internalisation, and the absence of a thermal inactivation step. Crucially, evidence indicates that standard post-harvest interventions, such as washing, are largely ineffective due to pathogen protection within plant tissues. Furthermore, the review addresses current regulatory gaps, arguing that existing classifications fail to distinguish the unique risk profile of microgreens from both sprouts and mature greens. Consequently, safe integration requires species-specific risk assessment, verified seed quality, and reinforced hygiene practices across production and food service settings.

Keywords

microgreens; functional foods; food safety; microbiological risk; ready-to-eat foods; gastronomy

Over the past decade, modern gastronomy has assumed a prominent role in the socio-economic landscape, influencing economic growth, tourism, and contemporary dietary culture [1]. This evolution is driven by an emphasis on high-quality dining experiences and the incorporation of novel ingredients like microgreens [2, 3]. While often perceived as a contemporary trend, the culinary use of microgreens, originating in San Francisco during the 1980s, has evolved from a niche garnish into a globally recognised phenomenon [4].

Crucially, the definition of microgreens necessitates a strict biological distinction from sprouts, a nuance that directly impacts their regulatory status. Microgreens are young edible plants harvested by cutting the stem above the root system when cotyledons are fully developed and first true leaves emerge (7–14 days post-germination) [5]. Unlike sprouts, which are consumed intact (including the root and seed), this method of harvesting has historically exempted microgreens from the rigorous safety controls applied to sprout production, despite both being cultivated under warm, humid conditions ideal for pathogen growth.

Despite their small size, they offer intense flavours and vivid colours, satisfying the concept of "visual hunger" described by SPENCE et al. [6] and CHATTERJEE and JOSHI [7]. Visual appeal plays a decisive role in consumer acceptance. MICHELL et al. [8] reported that participants expressed a strong willingness to purchase microgreens after tasting, largely driven by positive sensory perception and flavour familiarity.

Beyond sensory attributes, microgreens are increasingly classified as functional foods with the potential to address "hidden hunger" [9]. They act as dense reservoirs of phytonutrients, frequently exhibiting superior nutritional value compared to mature counterparts [3]. XIAO et al. [5] demonstrated that microgreens may contain 4–40 times higher concentrations of bioactive compounds, including vitamins such as carotenoids, ascorbic acid, tocopherols, and phylloquinone. Species-

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specific profiles further enhance this value: *Brassicaceae* are rich in glucosinolates [3], while species like fenugreek are recognised for their potential in managing metabolic disorders such as diabetes [9].

The socio-economic relevance of microgreens is closely linked to urban agriculture (UA), contributing to food security by shortening supply chains. As reported by TENG et al. [10] and BARAŃSKA et al. [11], vertical farming systems reduce transportation requirements and improve access to nutrient-dense foods in metropolitan "food deserts." Microgreens are well suited to these systems due to their short growth cycle and high economic value. Production is predominantly based on controlled environment agriculture (CEA), allowing precise regulation of growth parameters to standardise quality [12]. According to SETH et al. [9], the global market was projected to reach 17.04 billion USD (17.04×10^9 USD) by 2025, driven by the rapidly growing demand for functional and nutrient-dense foods.

Despite their widespread promotion as fresh, natural and nutrient-dense foods, microgreens are predominantly consumed as raw, ready-to-eat products and therefore warrant careful food safety consideration [13]. Although historically considered safer than sprouts, which have been linked to numerous foodborne disease outbreaks, recent data suggest growing safety concerns. Multiple recalls of commercial microgreens due to contamination with *Salmonella* and *Listeria monocytogenes* highlight the vulnerability of this fresh product to pathogen proliferation, particularly given the lack of thermal processing prior to consumption [12]. Their cultivation relies on warm and humid conditions that are optimal for rapid plant growth but also favourable for the survival and proliferation of these foodborne pathogens. In addition, experimental evidence indicates that pathogenic microorganisms may internalise into plant tissues during early developmental stages, limiting the effectiveness of surface-based sanitisation strategies [2, 12, 13]. This challenge of decontamination extends beyond bacteria to viral pathogens, where surface characteristics play a decisive role. While human norovirus (HuNoV) is widely recognised as a primary safety concern across the entire fresh produce sector, specific investigations into microgreens reveal that leaf surface morphology plays a critical role in viral persistence [14].

At the same time, consumer perception is heavily driven by visual freshness, natural origin and functional food narratives [8], creating a "health halo" effect that may obscure safety risks [15]. This perceptual bias contributes to the systematic underestimation of microbiological risks associated with microgreens, thereby reinforcing the conceptual tension between their perceived health benefits and their underlying food safety challenges.

The objective of this review is to critically examine the integration of microgreens into modern gastronomy by addressing their nutritional value, culinary relevance and microbiological risk profile across the production and consumption chain. The review is guided by the central hypothesis that the same biological and production characteristics that underpin the nutritional density and sensory appeal of microgreens also contribute to their underestimated food safety risks. By synthesising evidence from agronomy, nutrition, food microbiology and gastronomy, this work aims to provide a framework for risk-aware integration of microgreens into professional food service.

Review methodology

Relevant literature was systematically searched across Web of Science (Clarivate Analytics, Philadelphia, USA), Scopus (Elsevier, Amsterdam, Netherlands), PubMed (National Library of Medicine, Bethesda, Maryland, USA), and Google Scholar (Google, Mountain View, California, USA), covering publications from 2003 to 2026. The search utilised Boolean combinations of keywords: ("microgreens" OR "sprouts" OR "baby leaf vegetables") AND ("controlled environment agriculture" OR "phytochemicals" OR "food safety" OR "regulation"). Inclusion was restricted to English- and Serbian-language, peer-reviewed articles with full-text availability. After excluding preprints, abstracts, and duplicates, the final selection focused on cultivation systems, post-harvest practices, and raw consumption risks.

Microgreens: biology, diversity, and market

While young seedlings have long been consumed in Asia for their therapeutic properties [16, 17], the modern gastronomic concept of "microgreens" originated in late-1980s San Francisco. As noted by SETH et al. [9], chefs initially utilised them as "vegetable confetti", primarily arugula, basil, and cilantro, to introduce flavour complexity and visual appeal. Since then, microgreens have evolved from a niche garnish into globally recognised fine-dining ingredients, functioning as both sensorial tools and visual signatures [3]. Over the past decade, this chef-driven innovation expanded into premium retail and health-food markets, positioning microgreens as nutrient-dense salad alternatives [8, 18, 19]. Market dynamics are now driven by a feedback loop between producers, chefs, and consumers, based on sensory appeal and perceived health benefits [20], transforming microgreens into a global product category.

Microgreens are distributed as fresh-cut products or growing on media ("living microgreens") for end-user harvesting [2, 3]. Microgreens encompass a wide botanical diversity, with commercially exploited species originating from several major plant families. Among these, *Brassicaceae* dominate production due to their rapid growth, intense flavour and high phytochemical content (e.g., broccoli, radish, arugula), followed by *Apiaceae* (e.g., cilantro, parsley) and *Amaranthaceae* (e.g., spinach, amaranth), which are valued for their nutritional density and mild sensory profiles. Additional families include *Alliaceae* (e.g., chives, scallions), *Asteraceae* (e.g., lettuce, sunflower), *Fabaceae* (e.g., pea shoots, fenugreek), and *Lamiaceae* (e.g., basil, mint), while other groups such as *Poaceae* (e.g., corn), *Polygonaceae* (e.g., buckwheat) and *Portulacaceae* (e.g., purslane) are used more selectively depending on culinary application and market demand [2].

Despite their botanical diversity, commercial cultivation is predominantly standardised through Controlled Environment Agriculture (CEA). By enabling precise microclimate control, particularly regarding lighting and irrigation, these systems optimise urban vegetable production models such as vertical farms, greenhouses, hydroponics, and aquaponics [17, 21–23]. Moreover, CEA offers a sustainable alternative to traditional agriculture by reducing resource depletion [24]. Currently, this technology drives the intensification of production [23], particularly regarding "microscale vegetables" – a collective category encompassing sprouts, microgreens, and baby leaves [3, 12]. As CEA is utilised for various immature plants, distinguishing their safety profiles is crucial. Although sprouts, microgreens, and baby leaves share morphological similarities, they represent distinct physiological stages with specific risks.

Sprouts are legally defined as immature plants (including root and stem) germinated via seed immersion (8–12 h) and cultivated in humid, low-light conditions (21–27 °C) for 3–10 days [12, 24]. Safety-wise, these conditions favour rapid microbial proliferation, making internal seed contamination the primary vector since the entire organism is consumed [2, 10, 12]. Microgreens lack a universal legal definition but are classified as germinated plants with fully developed cotyledons [25]. Unlike sprouts, they are harvested by cutting the stem above the soil line at 7–14 days [2, 26]. The safety concern shifts from the root to the harvest interface; the cut surface creates a potential entry point for surface pathogens during handling [12, 13]. Consequently, safety relies heavily on good agricultural practices (GAP) and strict hygiene during the hospitality "cut-and-serve" phase [27]. Baby leaf vegetables represent an advanced stage, harvested when true leaves develop (20–40 days). Frequently grown in open fields or semi-open greenhouses [12, 28], their risk profile is tied to environmental exposure, including water quality, soil amendments, and wildlife intrusion [29].

Clear differentiation between sprouts, microgreens, and baby leaf vegetables is a prerequisite for the precise identification of critical control points (CCPs). Once microgreens are distinctly separated from related product categories, the subsequent step involves examining how their specific biological characteristics translate into distinct contamination pathways and control points throughout the production chain. This analysis is essential for establishing a proactive food safety assurance system [30] based on pre-harvest controls.

Production chain: from seed to fork

Microgreen production encompasses a series of sequential steps that can be categorised into five distinct operational phases:

- pre-cultivation and inputs,
- cultivation and growth,
- harvesting,
- post-harvest handling, and
- distribution and consumption.

Each phase presents specific agronomic requirements and CCPs, thereby directly determining the overall quality and safety of the final product.

Phase 1 – Pre-cultivation and inputs

The first phase encompasses seed selection, media selection, and sowing procedures. During germination, the enzymatic degradation of stored nutrients increases bioavailability and water content, transforming the seed into a pathogen amplification site [12, 31–33]. Consequently, preventing initial seed contamination is critical. High bacterial loads at this stage promote early internalisation – likely via stomata – rendering subsequent post-harvest decontamination ineffective [2, 12, 13, 34]. Beyond microbiological hazards, distinguishing edible species is essential. As emphasised by SETH et al. [9], *Solanaceae* (e.g., tomato, eggplant) must be excluded; unlike mature fruits, their cotyledons contain toxic glycoalkaloids like solanine, posing gastrointestinal and neurological risks.

Following seed selection, the growing medium plays a fundamental role. Although physical abiotic factors influence microbial multiplication, they alone cannot determine pathogen contamination levels [12], particularly as microgreens are cultivated in open-air or indoor systems using varying soil or soilless substrates [35]. Ideally, these substrates must possess optimal physicochemical properties, including high water-holding capacity and adequate aeration, to support rapid root growth without waterlogging [3]. While peat-based mixes are traditionally used, sustainability concerns have prompted a shift towards renewable natural fibre mats (e.g., jute, hemp, kenaf) [3]. These inert substrates are particularly valued in hydroponic systems for enabling cleaner production and precise nutrient management compared to bulk substrates (e.g., peat moss, soil mixes) [2].

Finally, sowing density requires careful control based on germination testing, typically ranging from 3 to 4 seeds per square centimetre [36]. Although high densities increase yield, they reduce mean shoot weight [37] and restrict air circulation. This creates humid microclimates favouring fungal proliferation (damping-off) and compromises visual quality through etiolation [38], making density a key safety and quality determinant. Crucially, while increasing seeding density optimises yield, it creates a dense canopy architecture that traps moisture at the hypocotyl level. This induced microclimate significantly elevates water activity, thereby facilitating the rapid horizontal migration of pathogens from a single contaminated seed to the entire batch.

Phase 2 – Cultivation and growth

The cultivation phase represents the core physiological development of microgreens, typically divided into two stages: an initial dark germination phase followed by a light-dependent photosynthetic phase [3]. Early germination in darkness and high humidity promotes uniform emergence, while subsequent light exposure initiates autotrophic growth and bioactive synthesis.

Lighting is a central factor in controlled environment agriculture, with a documented transition to light-emitting diodes (LEDs) due to their energy efficiency and suitability for vertical farming [39]. Studies demonstrate that light quality strongly influences morphology, sensory attributes, and phytochemical composition [3]. Generally, red and blue wavelengths enhance photosynthetic efficiency and biomass, while increased blue light stimulates the synthesis of secondary metabolites like anthocyanins [38, 40]. These responses are species-specific, requiring optimisation to balance yield and nutritional quality [17, 41].

Beyond lighting, abiotic factors such as temperature, humidity, and substrate pH play a critical role in product quality and safety. Optimal temperatures typically range from 18 °C to 25 °C; however, excessive heat and high humidity create ideal conditions for pathogenic bacteria [42, 43]. Therefore, precise environmental control is essential to balance phytochemical accumulation with microbiological safety [10]. It is important to emphasise that agronomic practices aimed at maximizing yield, such as maintaining high relative humidity and temperatures between 20–25 °C, directly antagonise safety standards by creating conditions that overlap precisely with the proliferative optimum for mesophilic pathogens.

Irrigation and nutrient management further influence physiology and safety. Bottom watering and moderate nutrient inputs are preferred to minimise canopy wetness and prevent pathogen dissemination associated with overhead irrigation [42]. While microgreens rely largely on endogenous reserves, strategic nutrient management is necessary to avoid depletion and ensure quality [38]. Excessive fertilisation thus presents a dual risk: nitrate accumulation [38] and pathogen proliferation in nutrient-rich hydroponic environments [12, 35]. Consequently, cultivation is a critical stage where agronomic optimisation and risk management must be addressed concurrently.

Phase 3 – Harvesting

The harvesting phase represents a critical control point influencing both microbiological safety and post-harvest quality. Typically performed 7–21 days post-germination (seedling height 5–10 cm), this stage occurs when cotyledons are fully expanded and first true leaves emerge [2, 3, 25, 26]. Manual harvesting necessitates strict hygiene, as handling is a documented contamination source [12]. Sharp, sanitised tools are crucial to minimise tissue damage that facilitates pathogen internalisation [12, 13, 35]. To minimise risks, the “living microgreens” model transfers final harvesting to the end-user [3].

Phase 4 – Post-harvest handling

Rapid post-harvest deterioration is a principal constraint to commercialisation. Due to high surface-area-to-volume ratios, elevated respiration, and delicate tissues, microgreens are highly perishable and prone to wilting and decay [2, 44]. To preserve freshness, some producers market “living products” (typically on hydroponic pads), allowing harvest immediately prior to use [3, 45].

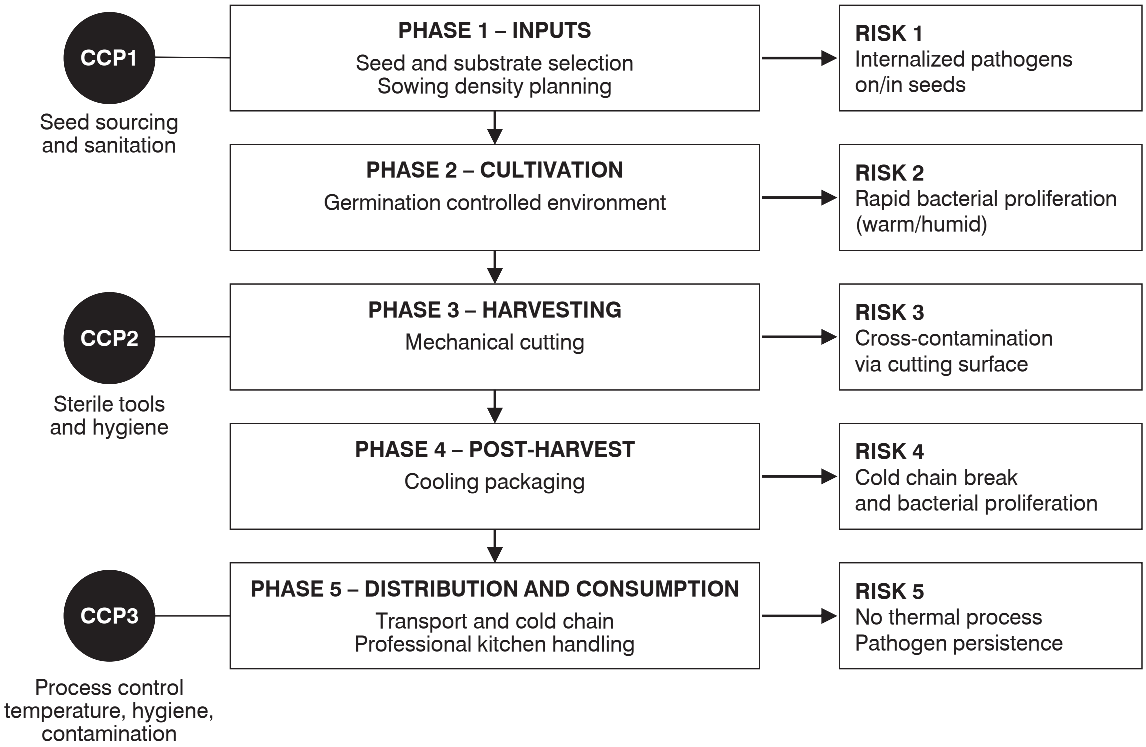

Fig. 1. Schematic overview of the microgreen production chain identifying critical control points.

However, even living microgreens require rapid utilisation to maintain sensory quality [2]. For cut products, handling focuses on managing physiological stress. High metabolic activity and exposed cut surfaces result in respiration rates exceeding those of mature vegetables, causing rapid dehydration and nutrient degradation [3]. Consequently, the primary objective is suppressing respiration through strict temperature control, while often avoiding post-harvest washing to prevent moisture-induced decay [2].

Packaging plays a pivotal role in regulating the microenvironment; specifically, modified atmosphere packaging (MAP) is widely employed to reduce O_2 and elevate CO_2 levels, effectively slowing respiration without inducing anaerobic fermentation [3]. Within this system, film selection is a critical variable, as improper gas permeability may cause tissue injury or promote anaerobic pathogen growth. Under such optimal conditions, combining proper cooling with MAP, shelf-life typically ranges from 10 to 14 days, representing a significant extension compared to the 1–2 days observed at ambient temperatures [2, 3, 45]. Additionally, packaging must provide physical protection, as tissue crushing rapidly leads to necrosis and microbial decay [2].

Kou et al. [44] showed that calcium chloride ($CaCl_2$) dips maintain firmness and delay senescence. More recently, Sobhanan et al. [46] developed biodegradable *Aloe vera*-based edible coatings for *Brassica juncea* and *Lactuca sativa*, achieving significant spoilage reduction. Additionally, active nanopackaging incorporating antimicrobial agents has been reported to inhibit respiration and spoilage more effectively than conventional coatings [47], offering promising solutions for stabilising bioactive compounds.

Maintaining an uninterrupted cold chain (1–4 °C) is essential to suppress respiration and inhibit the growth of psychrotrophic pathogens; temperature breaches accelerate senescence and risk pathogen bacteria proliferation, especially *Listeria monocytogenes* [3, 12, 43].

When it comes to washing, it presents a point of contention concerning both its impact on quality and microbial safety. From a quality perspective, excessive moisture accelerates deterioration; therefore, many producers market “unwashed” products harvested above the substrate [3]. From a safety perspective, however, the efficacy of washing is fundamentally limited by the prior internalisation of pathogens within plant tissues [2, 12, 13, 34], meaning that surface sanitation cannot access nor eliminate bacteria sequestered inside the vascular system. Furthermore, wash water can facilitate cross-contamination if not properly managed [12]. If washing is nevertheless employed, strict water quality control, the use of sanitising agents, and effective dewatering (e.g., centrifugation) are essential to minimise free moisture that promotes microbial growth and decay [2, 3, 12].

Phase 5 – Distribution and consumption

The final phase of bringing microgreens to market presents the greatest challenges, as control shifts from the producer to the end-user, whether in food service or the domestic kitchen. Microgreens are sold as "fresh-cut" or "living" (in growing trays), with the "living" format maximising freshness by avoiding the wounding stress associated with harvesting [3]. However, this simultaneously transfers critical safety control points, harvesting and hygiene, to end-users who are often unaware of the associated risks [2, 12]. Despite their health "halo", inadequate handling practices (poor refrigeration, cross-contamination) significantly increase the risk, as the product is consumed raw [12, 43]. Responsibility for potential washing now falls to the consumer, but inconsistent labelling and a lack of handling guidelines render this measure uncertain and potentially counterproductive [2, 10, 12]. These end-of-supply-chain vulnerabilities are illustrated in Fig. 1, which summarises this shift in risk profile and provides a framework for the analysis in the following sections. Understanding the entire production chain is crucial both for safety assessment and for interpreting the unique nutritional properties of microgreens, which arise from their early developmental physiology and controlled cultivation conditions.

Nutritional and phytochemical profile

Microgreens, frequently termed "superfoods" [11], represent a unique phenophase characterised by intense metabolic activity. During this stage, the seedling mobilises endogenous reserves to fuel rapid biosynthesis, resulting in a phytonutrient profile drastically different from sprouts or mature plants [48]. Due to their compact biomass and exceptional density, microgreens are identified not merely as a culinary trend but as strategic "functional foods" capable of addressing hidden hunger [10, 11].

Beyond terrestrial agriculture, microgreens are pioneered as key components of "space life support systems" (SLSSs). NASA identifies them as ideal for long-duration missions due to their rapid growth, minimal resource requirements, and high nutrient density [49]. As noted by SETH et al. [9], their ability to thrive on synthetic media under low photon flux makes them an optimised choice for astronaut diets. Beyond nutrition, these crops provide vital antioxidants to mitigate space-radiation-induced oxidative stress and offer significant psychological relief for isolated crews [3, 9]. While positively influencing willingness to pay [7, 18], this perception may lead consumers to underestimate microbiological risks [18, 20], underpinning the "gastronomic paradox", where visual purity masks potential safety hazards.

Regarding bioactive profiles, species within *Brassicaceae* are particularly noted for cancer-protective compounds, including glucosinolates and carotenoids, which also exhibit significant antimicrobial properties [48]. Beyond these, families such as *Amaranthaceae*, *Apiaceae*, and *Lamiaceae* offer distinct health benefits through their diverse complex secondary metabolite profiles [45]. Expanding this landscape, SOUMYA et al. [50] evaluated seed spice microgreens (e.g., cumin, fennel, fenugreek), revealing that these species are not only potent mineral sources but also exhibit a distinct compositional diversity, particularly in their essential oil-derived bioactives. This confirms that the intense metabolic activity of the seedling phase amplifies the nutritional profile significantly beyond that of the mature plant [48, 50].

Micronutrient density

Microgreens' superiority lies in their exceptionally high micronutrient concentrations compared to mature counterparts. Research on 25 species demonstrated significantly elevated levels of phylloquinone, ascorbic acid, and tocopherols, with red cabbage microgreens providing nearly three times the vitamin C of the mature vegetable [5, 48]. Beyond vitamins, microgreens exhibit superior mineral profiles, specifically in magnesium, manganese, and sulphur in broccoli, as well as calcium and potassium in lettuce, driven by aggressive nutrient uptake during the hypocotyl development stage [3, 51, 52]. Crucially, the microgreening process enhances mineral bioavailability by significantly degrading anti-nutritional factors like phytic acid, a biochemical transformation that is particularly vital for the nutritional optimisation of cereal, pseudocereal, and spice species [50, 53].

Furthermore, microgreens are identified as pivotal candidates for "agronomic biofortification" strategies [16]. Deliberate enrichment of hydroponic solutions with selenium (Se), zinc (Zn), and iodine (I) transforms microgreens into potent vehicles for addressing human nutrient deficiencies [16]. This nutritional malleability is evidenced by buckwheat microgreens, where specific Se and I treatments not only optimise the metabolic profile but boost biomass yield by up to 70 % [16, 54]. Similarly, Se-enrichment has been confirmed to boost antioxidant capacity without compromising yield [16, 38]. Crucially, as highlighted by PARTAP et al. [55], unlike synthetic supplements, biofortified microgreens deliver these minerals in organic, highly bioavailable forms. This transition not only improves human nutrient status but simultaneously enhances the plant's own antioxidant defence mechanisms [16, 48].

Phytochemical diversity and functional bioactives

Beyond basic nutrition, microgreens are classified as "functional foods" with therapeutic potential [16]. Their bioactive secondary metabolites, synthesised as stress defence mechanisms during germination, play a pivotal role in mitigating oxidative stress and preventing chronic diseases [48]. Chemical profiles are family-dependent: *Lamiaceae* are rich in polyphenols, while *Brassicaceae* are defined by glucosinolates [19, 56, 57].

The therapeutic efficacy of *Brassicaceae* relies on the hydrolysis of glucosinolates into isothiocyanates (e.g., sulforaphane) by the enzyme myrosinase. BHASWANT et al. [57] highlight that these compounds activate the Nrf-2 (nuclear factor-erythroid 2 related factor 2) signalling pathway, a master regulator of cellular antioxidant defence. As reviewed by ZHANG et al. [23], this mechanism underpins their chemo-preventive properties, including significant anti-proliferative activity against colon cancer cells.

Microgreens specifically modulate chronic disease pathways. Regarding cardiovascular health, SHARMA et al. [16] highlight findings by HUANG et al. [58] that red cabbage microgreens alter lipid metabolism, reducing low-density lipoprotein cholesterol and hepatic triglycerides more effectively than mature cabbage. For metabolic disorders, SETH et al. [9] identify fenugreek and coriander microgreens as effective inhibitors of the alpha-glucosidase enzyme, offering a mechanistic approach to managing postprandial glycaemia. Additionally, they effectively address "hidden hunger": high concentrations of bioavailable iron and zinc in species like amaranth help mitigate anaemia [9, 55].

However, safety assessments are essential. SETH et al. [9] warn that certain *Amaranthaceae* species (e.g., spinach) act as hyper-accumulators of oxalates. Mitigation requires harvesting at the optimal maturity stage (true leaf emergence) to reduce oxalate levels [16].

Sensory profile and consumer perception

In the context of gastronomy, sensory properties are decisive. Microgreens have evolved from simple "edible garnishes" to essential culinary components that shape the dining experience beyond mere decoration [8]. Their vivid colours and delicate morphology create a strong multisensory impact, reinforcing the notion that "food is first eaten with the eyes" [20].

This visual complexity is intrinsically linked to the concept of "visual hunger", whereby aesthetically appealing foods stimulate appetite and perceived value, particularly in fine dining and social media-driven cultures [6]. Chefs primarily value this "sensory quality" to signal modernity and craftsmanship. Simultaneously, they utilise species-specific flavour fingerprints – such as the pungency of *Brassicaceae* (derived from glucosinolate breakdown into isothiocyanates) or the sweetness of pea shoots – to construct complex "flavour architectures." This allows for the modulation of taste and provides critical textural crispiness (turgor pressure) without altering the dish's volume [8, 10].

However, a distinct gap exists between culinary appreciation and general consumer acceptance. A significant "bitterness threshold" limits the mass adoption of pungent varieties, despite their popularity in gastronomy [4]. This suggests a strategic market bifurcation: visually complex, intense varieties are suited for high-end gastronomy (satisfying "visual hunger"), while milder, familiar-tasting varieties (e.g., red cabbage) are key to penetrating the mass retail market where flavour familiarity outweighs visual novelty [4, 8].

Production techniques, such as specific LED recipes (e.g., blue light dosage), are increasingly used to "design" these sensory traits by stimulating secondary metabolites [38, 59]. Ultimately, the strong association between vivid appearance and freshness contributes to a "health halo" [15].

The „nutritional paradox“ of microgreens

A critical debate in gastronomic nutrition concerns the „serving size paradox“: can typical 2–10 g servings truly impact health? The answer lies in distinguishing nutrient density from absolute intake. Microgreens function as „high-efficiency functional foods,“ offering targeted therapeutic benefits even in culinary doses [4, 16]. However, quantitative realities exist: a 5 g serving of micro-red cabbage provides approximately 7.35 mg of vitamin C, whereas 100 g of the mature vegetable provides 57.0 mg [5, 51]. Consequently, microgreens should not be viewed as volumetric replacements for bulk vegetables, but as functional enhancers that synergistically improve the bioactive profile of a meal without increasing its volume [4, 48].

From a bioavailability and sustainability perspective, the nutritional density of microgreens is further reinforced by their highly resource-efficient production systems. Compared with conventional vegetables, microgreens deliver concentrated bioactive compounds in small portions and are particularly well suited to controlled environment agriculture (CEA) and urban farming [16, 38]. Recent studies position them as a promising component of sustainable food systems rather than merely a culinary trend [3, 10]. Therefore, while microgreens serve as a nutrient-dense food and a model for sustainable production, their inherent physiology creates an inevitable trade-off that necessitates rigorous food safety management [10, 38].

Food safety and microbiological risks

Microgreens constitute a microbiologically sensitive food category due to their raw, ready-to-eat nature and the absence of a thermal inactivation step. Although epidemiologically associated with fewer outbreaks than sprouts, they share critical risk vectors with other microscale vegetables, including potential seed-borne contamination, favourable environmental conditions for pathogen proliferation, and the limited efficacy of post-harvest decontamination interventions [2, 4, 12, 13].

Microgreens occupy a complex intermediate position characterised by a "regulatory-biological mismatch". While harvested above the seed line, leading to their frequent exclusion from sprout-specific protocols, from a biological and operational perspective, they more closely resemble sprouts than mature greens. It is crucial to distinguish the epidemiological profiles of sprouts, microgreens, and baby leaf vegetables. These categories, while visually similar, have distinct safety histories and primary contamination routes.

Sprouts have a well-documented history as the cause of major foodborne illness outbreaks, resulting in stringent regulatory frameworks. In the United States alone, between 2016 and 2022, four outbreaks linked to sprouts were recorded, caused by *Salmonella enterica* and *Escherichia coli* species [12]. Similar trends have been reported in Canada, confirming seeds as a critical contamination vector for this category [12].

Microgreens have a different, yet alarming, epidemiological record. While not yet associated with large-scale illness outbreaks, there is clear evidence of pathogen presence. In recent years, regulatory authorities in the USA and Canada have issued multiple recalls of microgreens due to the detection of *Salmonella* spp. and *Listeria monocytogenes* [2, 12]. The fact that these incidents are detected through surveillance, despite a lack of reported illnesses, indicates a latent hazard and likely contamination at the production level [2, 10, 12]. This suggests that, with the expansion of industrial production, microgreens may follow an epidemiological trajectory similar to sprouts, as they share seeds as a fundamental source of risk [2, 10, 12].

In contrast, baby leaf vegetables (such as young lettuce) represent a third, clearly distinct profile. For them, risks arise not primarily from seeds but from pre-harvest environmental factors, such as contaminated irrigation water or contact with wildlife [12, 13]. This highlights a fundamental difference in contamination pathways compared to sprouts and microgreens, despite their superficial similarity [12, 29]. This clear distinction in risk sources (seeds vs environment) and epidemiological history (outbreaks vs product recalls) has direct implications and necessitates specific, tailored approaches to food safety control for each of these product categories.

Bacterial hazards

The bacterial hazard profile associated with microgreens is predominantly characterised by members of the *Enterobacteriaceae* family, which serve as both hygiene indicators and reservoirs of human pathogens [10, 12]. According to a comprehensive review by TURNER et al. [2], the microgreen industry has experienced multiple product recalls in North America, most frequently linked to *Salmonella* spp. and *Listeria monocytogenes* [2, 12]. Although confirmed outbreaks are less frequent than those associated with sprouts, the risk remains substantial, as *Salmonella* can survive for extended periods in low-moisture environments such as stored seeds and subsequently proliferate rapidly upon hydration during germination [2, 13]. Of particular concern is *Listeria monocytogenes*, which differs fundamentally from *Salmonella* in its ability to survive and multiply at refrigeration temperatures [2, 38]. Given that microgreens are typically marketed in high-humidity clamshell packaging and distributed under refrigerated conditions, these products may inadvertently provide favourable conditions for *Listeria* growth, allowing low-level contamination to increase to potentially infectious levels by the end of shelf life [12, 38].

Unlike *Salmonella*, which is most commonly introduced via contaminated seeds, *Listeria* is ubiquitous in processing environments and readily colonises damp surfaces such as growing trays, irrigation lines, and harvesting equipment, where it can establish persistent biofilms [12, 13]. Although reported less frequently, Shiga toxin-producing *Escherichia coli* (STEC) has also been isolated from microgreen production systems. Experimental studies have demonstrated that *E. coli* O157:H7 can proliferate rapidly during the short growth cycle of microgreens, indicating that even low initial contamination levels may reach infectious doses within 7–14 days [35]. However, recent findings by Rao et al. [60] indicate that this risk is not uniform across species. Their work showed significantly higher persistence of *Salmonella* on red cabbage microgreens compared with daikon radish, suggesting that leaf surface characteristics such as topography and cuticular wax composition play a decisive role in shaping pathogen survival and attachment.

Viral hazards

Beyond bacterial hazards, the status of microgreens as raw, ready-to-eat products also exposes them to viral contamination, particularly human norovirus (HuNoV), the leading cause of viral gastroenteritis associated with fresh produce [61]. The absence of thermal processing means that viral particles introduced via contaminated water or infected food handlers remain infectious until consumption. Deng and Gibson [14] identified leaf morphology as a key determinant, showing that complex pea shoots retain viruses significantly longer than smooth sunflower leaves. Unlike bacteria, which can internalise into plant tissues [62], viruses do not replicate on plants but instead persist on the surface as passive transmission vehicles [14, 63]. Consequently, viral contamination in microgreens is predominantly vector-driven, linked primarily to infected handlers [13] or contaminated irrigation water [63], making strict hygiene and water quality control the primary defence against viral outbreaks.

Seed-borne internalisation

The primary source of contamination within the microgreen production chain is unequivocally the seed, a reality that underscores the central concept of pathogen internalisation for this product‘s safety. According to the seminal findings of Warriner et al. [62], the nutrient-rich exudates from germinating seeds serve as chemoattractants, drawing bacteria into the rhizosphere. Driven by this chemotactic response, pathogens such as *Salmonella* spp. and *Escherichia coli* migrate toward roots and penetrate plant tissues through natural openings, including stomata, or through micro-injuries associated with lateral root emergence. Once internalised within the apoplastic space and vascular system (xylem), pathogens become effectively protected. This biological mechanism explains why post-harvest washing cannot be considered a reliable CCP for microgreens. Taken together, these findings reveal a critical operational paradox: although washing is widely perceived as a fundamental food safety intervention, in microgreen production it offers limited protection and may, under certain conditions, contribute to cross-contamination through wash water and excess surface moisture [2, 12, 13, 34].

The problem is further compounded by a confluence of risk factors. Key seed characteristics, such as surface morphology and weight, have been shown to influence pathogen transfer. This is particularly problematic in species with mucilaginous seed coats, like cress, where bacterial adhesion is facilitated, leading to high transfer rates [64]. Furthermore, studies confirm exponential pathogen growth during the germination phase across various species, including alfalfa, mung bean, and spinach sprouts for *Salmonella enterica* [65] and radish and alfalfa for pathogenic *E. coli* [35]. The production environment can also support the persistence and potential growth of other hazards, such as *Listeria monocytogenes* [66]. Eradication is complicated by the pathogens’ ability to form resistant biofilms [12, 13, 67].

Unlike sprout seeds, microgreen seeds rarely undergo aggressive decontamination. Since standard washing is often insufficient [38], effective seed-level interventions are required, such as chemical disinfectants, organic acids [68], or emerging technologies like cold plasma treatment, which can reduce microbial loads while sometimes stimulating growth [69].

However, the phenomenon of internalisation ultimately dictates that reliance on any single post-harvest or seed treatment step is insufficient to guarantee complete safety [35, 66]. This underscores a fundamental principle: effective risk management must be pre-emptive, focusing on seed safety and tightly controlled early production phases, as later interventions are inherently limited by the biological barrier of internalised contamination.

Production systems and substrates

Beyond pathogen identity, the choice of production system and growing medium fundamentally determines microbiological risk. The central distinction lies between soil-based systems, which can partially suppress pathogen proliferation through competitive native microflora, and hydroponic or soilless systems, which are widely adopted for microgreen production yet present specific vulnerabilities.

In inert hydroponic environments lacking a competitive microbiome, pathogens introduced via contaminated seeds or irrigation water can spread rapidly through recirculating nutrient solutions, potentially contaminating entire batches within hours [10, 35, 60]. Unlike soil, which can act as a filter, the recirculating water in hydroponics acts as a rapid dissemination vector, distributing contaminants from a single point source to the entire crop. The typically high humidity of these systems further promotes the persistence and biofilm formation of pathogens like *Listeria monocytogenes*, complicating sanitation [13]. Studies confirm that hydroponic systems are associated with significantly higher pathogen survival and proliferation from contaminated seeds compared to soil-based systems [35]. For instance, pathogens such as *Escherichia coli* O157:H7 can reach higher levels in hydroponic media, likely due to uninterrupted moisture and the absence of microbial competition [35].

This vulnerability extends critically to the growing substrate itself. Contaminated soilless substrates act as potent pathogen reservoirs. Research by Işık et al. [64] demonstrated a high transfer potential of *Listeria monocytogenes* from perlite to harvested microgreens. Similarly, Chen et al. [65] reported that inert substrates (e.g., biostrate pads) can sustain higher pathogen populations than biologically active soils once contaminated, due to the lack of suppressive background microflora.

Furthermore, sustainable inputs like untreated harvested rainwater can introduce significant risk. Rao et al. [66] showed that rainwater can carry *Salmonella* and *E. coli* O157:H7 into systems, where these pathogens persist in the growing medium and act as long-term sources of re-contamination throughout the production cycle.

The risks associated with the growing medium directly translate to the harvesting phase. Harvesting involves cutting stems just above the substrate, a process that, while sometimes mechanical, is often manual and necessitates strict worker hygiene, as human handling is a documented contamination source [12]. It is critical to exclude any adhering substrate particles and residual seed integuments during this step, as these materials act as direct vectors for microbial transfer and can harbour pathogens [12, 35].

Moreover, the act of cutting inevitably causes tissue wounding and electrolyte leakage, creating exposed surfaces that facilitate pathogen internalisation and proliferation [12, 13]. Consequently, using sharp, regularly sanitised tools is essential to minimise tissue damage and associated risk. To optimise post-harvest quality, harvesting during early morning hours when respiration is low and tissue turgidity is maximal is recommended. Notably, the “living microgreens” model circumvents this critical step entirely by selling the uncut crop in its growing tray, thereby minimising handling risks and transferring the final harvest decision to the end-user [3].

Strategic nutrient management during production directly impacts both safety and quality. While adequate nutrition is essential for growth, excessive fertilisation poses a dual risk: it promotes nitrate accumulation [38] and creates nutrient-rich conditions that favour the proliferation and internalisation of human pathogens, particularly in hydroponic systems [12, 35].

Throughout distribution, strict maintenance of the cold chain (1–4 °C) is essential, as even minor temperature fluctuations accelerate respiration and enable the proliferation of psychrotrophic pathogens such as *Listeria monocytogenes* [3, 12, 43]. Conversely, a stable cold temperature significantly slows both metabolic activity and pathogen kinetics [3, 12].

Microgreen safety requires an integrated, preventative approach across the entire supply chain. Effective control relies on three fundamental pillars: ensuring seed safety to prevent pathogen internalisation, carefully managing growing conditions and inputs to avoid creating environments that favour pathogens, and maintaining an unbroken cold chain during distribution to suppress microbial growth. Success depends on aligning science-based practices, clear regulations, and informed handling by both producers and consumers.

Consumer perception and risk communication

The effective implementation of safety measures is ultimately constrained by a perceptual gap among consumers. Microgreens are marketed through “superfood” narratives, which create a powerful health halo. This cognitive bias leads consumers to systematically underestimate microbiological risks, as positive attributes like freshness, local origin, and organic production overshadow more complex hazard profiles [8, 15, 18]. Furthermore, this low-risk awareness reflects a broader systemic problem within the supply chain. Empirical data show that producers themselves are often unaware of specific hazards and regulatory obligations, relying primarily on informal, unverified online sources for safety information instead of standardised training [70]. While objective knowledge can reduce risk perception associated with novel technologies [18], general awareness of fundamental hazards – such as seed contamination, pathogen internalisation, and cold chain breaches – remains critically low among both consumers and parts of the industry [20, 71].

This gap between perception and reality directly undermines the effectiveness of safety communication. Therefore, targeted consumer education and clear, accessible labelling are essential to translate complex risk profiles into practical knowledge. Simultaneously, emerging sensor technologies are being explored as potential tools to increase transparency, including nanosensors for real-time freshness monitoring and biosensors for rapid pathogen detection (e.g., *Salmonella*, *Listeria*) [47, 56]. However, their broader application faces significant challenges. Beyond obstacles related to cost, scale, and validation [70], the very effectiveness of these technologies may be limited if they are not applied on the foundation of existing good production practices and clear procedures, whose absence HAMILTON et al. [70] highlight as a key vulnerability of the sector.

Microgreen chain and critical control points

Integrating the contamination pathways and biological vulnerabilities analysed in this chapter, Fig. 1 maps the production chain into a cohesive food safety framework. Unlike traditional models, this schematic highlights the critical continuum from seed sourcing to consumption, identifying three CCPs necessary to mitigate escalating risks. The process begins with inputs (phase 1), where CCP1 addresses the primary burden of internalised pathogens on seeds. As production shifts to cultivation and harvesting (phases 2–3), the focus moves to preventing bacterial proliferation in warm/humid environments and managing cross-contamination via cutting surfaces through sterile hygiene protocols (CCP2). Crucially, the schematic underscores a distinct operational shift post-harvest. While phases 1–4 allow for controlled interventions, phase 5 (distribution and consumption) introduces an often-uncontrolled environment characterised by the absence of a terminal pathogen reduction step. Consequently, any breach in the cold chain or lapse in hygiene protocols (risk 5) evolves into an immediate consumer hazard (CCP3), confirming that safety relies on rigorous process control extending into the professional kitchen [72, 73].

Risk management in professional kitchens

While agronomic practices largely determine the initial microbiological status of microgreens, their ultimate safety is frequently decided within the operational dynamics of professional kitchens. Unlike most vegetables that undergo thermal processing, microgreens are almost exclusively served raw to preserve their delicate texture and visual appeal. This gastronomic paradox arises from a direct conflict between culinary objectives, the preservation of thermolabile nutrients and delicate textures, and food safety imperatives, where the very methods used to maintain quality also serve as mechanisms that shield pathogens from external sanitary interventions. Nevertheless, observational evidence suggests that they are often handled with a level of informality typically reserved for low-risk garnishes [20, 71]. This chapter analyses the critical control points within the gastronomic workflow and proposes a practical risk-benefit framework for the use of microgreens across different food service contexts.

Although agricultural protocols emphasise pre-harvest safety, a critical blind spot emerges at the culinary stage: the operational reality of professional kitchens. In contrast to controlled industrial environments, restaurant kitchens are dynamic, high-pressure spaces in which hygiene protocols must coexist with the urgency of service [72, 73]. Consequently, the CCP 3 (risk 5) is defined in practice by four high-risk kitchen behaviours (Fig. 1).

Expanding on the “health halo” concept, this psychological factor significantly complicates operational food safety in professional kitchens. The classification of microgreens as “superfoods” is widely recognised for their dense nutritional profile [11, 74]. However, this positive “health halo” can inadvertently obscure potential biological risks. While consumers and chefs prioritise sensory appeal and health benefits [8], practical understanding of crucial safety protocols, such as proper sanitisation, remains inconsistent even among producers [70], creating a vulnerability in professional kitchens where visual quality often supersedes strict hygiene. Consequently, the risk of manual cross-contamination during final assembly, where microgreens are often arranged by hand as a finishing garnish [7], is heightened, as the step occurs after all thermal processing with no subsequent control. Similarly, the failure to maintain physical barriers during food handling, such as storing microgreens in open containers adjacent to raw animal products, creates a critical cross-contamination risk [70, 72]. These cognitive biases, perceiving “superfoods” as inherently clean, are methodologically treated as “human element” factors that can systematically degrade established standard operating procedures in high-pressure environments, such as professional kitchens [72]. This disconnect between perceived and actual risk underscores a critical operational gap: the same attributes that drive consumer demand (freshness, naturalness) can inadvertently undermine the strict handling practices required for a raw, ready-to-eat product, a dynamic emphasised in food-service risk models [72, 73].

In professional kitchens, the standard practice of washing microgreens is frequently omitted to preserve their delicate structure [3, 44], a decision supported by evidence that washing is ineffective against internalised, seed-borne pathogens [2, 10, 12]. This washing inefficiency is not merely a mechanical issue, but a methodological barrier caused by the internalisation of pathogens into plant tissues, which classifies microgreens as a high-risk product regardless of surface sanitation efforts. Consequently, the handling tool itself becomes the final control point. The routine use of sterile plating implements (e.g., tweezers) [2, 13, 35] must therefore be reclassified from a stylistic preference to a mandatory hygiene measure, ensuring the microbiological integrity established during production is not compromised at the final „science-to-table“ stage.

The practice of receiving „living“ microgreens in their growing substrate, common in food service to extend shelf-life and freshness, introduces a distinct hazard: it brings the growing medium, a documented reservoir for pathogens such as *Listeria monocytogenes* [13, 35, 64], directly into the plating environment. Harvesting (“cutting at the pass”) over or near the final dish risks transferring particles of soil or hydroponic mat onto the finished plate [72]. From a cross-contamination prevention standpoint, harvesting at the point of service (“at the pass”) is methodologically unsound, as the act of cutting directly over a finished dish is defined as an uncontrolled transfer of bio-aerosols and substrate particles onto the consumable product. Consequently, if living trays are used, harvesting must be performed in a separate preparation area with dedicated, sanitised tools, and never directly above a customer’s plate.

A critical yet often overlooked hazard occurs at the service pass, where plated dishes are held under heat lamps before collection. Microgreens placed on hot surfaces and exposed to the temperature danger zone (approximately 20–50 °C) risk rapid bacterial proliferation if service is delayed [72]. Concurrent loss of turgor pressure not only diminishes sensory quality but can also promote the release of nutrient-rich exudates on leaf surfaces, further facilitating microbial growth [35, 44].

Importantly, the “health halo” is not the only perceptual bias compromising kitchen safety. A related and dangerous misconception is the “flavour fallacy” – the assumption that sensory potency implies microbiological safety. The characteristic pungency of brassica microgreens (e.g., radish, mustard) stems from secondary metabolites like glucosinolates. However, empirical evidence demonstrates that these compounds, at physiological concentrations, fail to inhibit the proliferation of enteric pathogens. Indeed, studies confirm that *E. coli* O157:H7 can proliferate significantly on glucosinolate-rich radish microgreens during production [13, 35]. Consequently, mistaking strong flavour for sanitising power leads kitchen staff to treat these products with undue informality. Ultimately, the interaction between the “health halo” and “flavour fallacy” causes a perceptual downgrade of microgreens from sensitive ready-to-eat products to mere decorative elements, effectively dismantling the psychological barriers necessary for strict hygiene compliance.

Risk-benefit decision matrix in foodservice

The categorisation of microgreens as high-risk, ready-to-eat ingredients necessitates a paradigm shift from generic food safety guidelines towards a sector-specific risk management framework. As illustrated in Tab. 1, the decision to incorporate raw microgreens into a menu cannot be based solely on culinary aesthetics; it must be strictly governed by the establishment’s operational capacity to mitigate specific biological hazards, primarily *Listeria monocytogenes*, *Salmonella* spp. and pathogenic *E. coli* [2, 35, 65, 66]. This proposed matrix challenges the “one-size-fits-all” approach, advocating for a stratified regulatory stance based on consumer vulnerability and operational infrastructure. The risk categorisation in Tab. 1 is derived from a qualitative assessment model that correlates the level of operational control (cold chain integrity, sanitary infrastructure) with the probability of unintentional contamination during final preparation.

A critical divergence in the proposed matrix concerns healthcare and aged-care catering. Despite their superior phytochemical profile, the inclusion of raw microgreens in menus for immunocompromised populations represents an unjustifiable risk. Since these products do not undergo final thermal processing, the potential presence of *L. monocytogenes*, infectious at extremely low doses for vulnerable groups, creates a negative risk-benefit ratio [2, 15]. The marginal nutritional intake from a garnish is negligible compared to the mortality risk associated with listeriosis [75]. Consequently, the framework suggests that the use of raw microgreens in these settings should be strictly avoided as a necessary preventative control.

Moving down the risk spectrum, the matrix identifies mass catering (buffets) and street food as environments defined by a critical "hazard-control mismatch". In these high-volume settings, safety is compromised by inherent operational characteristics: prolonged exposure to the temperature danger zone, uncontrolled consumer behaviour, and frequently inadequate cold chain infrastructure [30, 72, 73]. The classification of street food as a "restricted" environment is further justified by empirical evidence showing that mobile food establishments frequently lack adequate facilities for hand hygiene and equipment sanitisation, with studies indicating that 100 % of surveyed vendors failed to meet comprehensive hygiene standards [76]. Due to these systemic limitations, the matrix advocates for a "restricted" status: unless microgreens are incorporated into dishes undergoing final thermal processing (e.g., soups, woks), they should be excluded from the menu to ensure pathogen elimination.

Conversely, the matrix permits the use of raw microgreens in fine dining, but this permission is conditional, not absolute. This distinction relies on the premise that high-end establishments possess the resources to implement "hurdle technology" at the service level: strict supplier vetting (GAP certification) [12, 13], dedicated cold storage, and the mandatory use of sterile plating tools (tweezers) to prevent human-to-food cross-contamination [2, 3, 12, 13, 35, 45, 72]. However, a critical limitation remains regarding the trend of bringing "living trays" (microgreens in substrate) into the kitchen. This introduces a vector for soil-borne pathogens and spores directly into the plating environment [13, 35, 64]. Therefore, while the sector is permitted to use the ingredient, the protocol must rigorously exclude substrate contact from the pass, relying on procedural discipline rather than thermal inactivation.

A critical link in this continuum remains the distribution phase, where even minimal temperature fluctuations (above 5 °C) during transport to the foodservice establishment can negate the effects of prior pathogen control measures (GAPs) [13, 72, 76].

In summary, the proposed decision matrix redefines microgreens as a "conditional luxury", an ingredient whose safety is intrinsically dependent on the context in which it is handled and served. These operational realities reveal a fundamental mismatch between biological risk and current regulatory oversight. Future regulatory approaches should reflect this stratification

Tab. 1. Risk–benefit decision matrix for microgreens in foodservice sectors.

Inherent risk profile	Gastronomic value	Management decision	Critical rationale and constraints
Healthcare and aged care sector (hospitals, nursing homes)			
Extreme (life-threatening)	Negligible (purely decorative)	Not recommended (zero tolerance)	Extreme vulnerability to *L. monocytogenes* (low infectious dose). The absence of final thermal processing creates an unacceptable mortality risk that outweighs negligible nutritional benefits [2, 15, 75].
Buffet and mass catering sector (hotels, event centres, cruises)			
High (uncontrolled exposure)	Moderate (visual garnish)	Restricted (heat-processed only)	Systemic "hazard-control mismatch" driven by temperature abuse and uncontrolled consumer cross-contamination. Raw service is unsafe; usage must be restricted to cooked formulations [30, 72, 73].
Street food / fast casual sector (high-volume, mobile units)			
High (infrastructure deficit)	Moderate (flavour profile)	Restricted (heat-processed only)	Critical infrastructure deficits (cold chain, sanitation) preclude safe raw handling [13, 72, 76]. Usage must be restricted to thermal applications (e.g., soups, woks) to ensure pathogen elimination
Fine dining sector (high-resource, controlled environment)			
Managed (mitigated risk)	High (integral sensory component)	Conditional permission (strict standard operating procedures)	Conditional permission relies on advanced "hurdle technology" (sterile tools, good agricultural practices sourcing). However, "living trays" pose a soil-borne hazard. Protocols must rigorously exclude substrate from the service pass to prevent cross-contamination [2, 3, 12, 13, 35, 45, 72].

by recommending stricter exclusions in high-risk demographic settings while requiring validated standard operating procedures in sectors where raw consumption is permitted.

Regulatory framework and standardisation

Microgreens lack a dedicated legal definition, leaving them in a regulatory "grey zone" between high-risk sprouts and general ready-to-eat leafy vegetables [13, 77]. Food safety agencies like the European Food Safety Authority (EFSA, Parma, Italy) and Food and Drug Administration (FDA, Silver Spring, Maryland, USA) heavily regulate sprouts, mandating strict controls like seed decontamination due to their outbreak history [77–79]. Although microgreens share similar warm, humid production environments, they are excluded from sprout regulations because they are harvested above the growth medium [13]. Instead, they fall under the broad, inadequate classification of "covered produce," despite unique risks like raw consumption [13].

This regulatory gap harms on-farm safety. Lacking science-based guidance, growers often rely on informal sources, leading to inconsistent hygiene [70]. Crucially, unlike sprout producers, microgreen growers are not required to decontaminate seeds. This allows the primary vector for pathogens like *Salmonella*, *E. coli* O157:H7, and *Listeria monocytogenes* to enter the supply chain unchecked [2, 35, 65, 66].

By forcing microgreens into ill-fitting categories, the current reactive framework creates inconsistent requirements and uneven consumer protection. A shift toward a proactive, risk-based regulatory category is essential. It would mandate targeted preventive controls, such as seed treatment and clear hygiene protocols, without imposing the disproportionate costs of full sprout regulations.

CONCLUSIONS

This review has critically examined the integration of microgreens into modern gastronomy, revealing their fundamental duality. On one hand, microgreens are dense reservoirs of bioactive compounds with sensory properties that define contemporary fine dining. On the other, they represent a microbiologically sensitive, ready-to-eat product whose biological and production traits, such as cultivation under warm, humid conditions, a short growth cycle, and the absence of a thermal inactivation step, create an ideal medium for pathogen internalisation and growth.

The synthesis of evidence leads to several pivotal conclusions. First, safety is determined at the beginning of the chain. The effectiveness of post-harvest washing is minimal due to the early internalisation of pathogens into plant tissues. Thus, the critical control point lies not in sanitation but in verified seed safety and controlled growing conditions. Second, a significant regulatory-biological mismatch exists. Current frameworks treat microgreens either as generic "fresh leafy produce" or exclude them from stricter sprout protocols, leaving them in a regulatory grey zone that fails to address their unique risk profile. Third, risk perception is distorted by a powerful "health halo". The marketing narrative of "superfoods" leads both consumers and food-service professionals to systematically underestimate microbiological risks, often treating microgreens as mere decoration rather than a high-risk, ready-to-eat ingredient.

Crucially, this review demonstrates that safe use must be context-dependent and moves beyond a "one-size-fits-all" approach. The proposed risk-benefit decision matrix (Tab. 1) provides a pragmatic, sector-specific framework for integration. This matrix challenges uniform guidelines by stratifying recommendations based on operational control and consumer vulnerability. It argues for the avoidance of raw microgreens in healthcare, aged-care, and mass-catering settings, environments characterised by a fundamental "hazard-control mismatch" or extreme consumer susceptibility. Conversely, conditional use is permissible in controlled environments like fine dining, provided strict operational protocols (aseptic handling, cold-chain integrity, sterile tools) are rigorously enforced. The matrix underscores that microgreens should be redefined as a "conditional luxury," whose safety is intrinsically tied to the context of handling and service.

Future research and practice must pivot toward: standardising commodity-specific challenge studies to quantify pathogen behaviour across species and growing systems; developing and validating effective seed-decontamination methods that do not compromise germination; formulating clear, distinct regulatory guidelines that acknowledge the hybrid risk profile of microgreens; and implementing targeted education to recalibrate risk perception within the gastronomic sector, elevating their handling to the level of other high-risk raw ingredients.

Ultimately, the sustainable and safe integration of microgreens requires a multidisciplinary approach that equally values their celebrated nutritional potential and their inherent microbiological vulnerability. Without this balanced perspective, the boundary between a functional superfood and a potential vehicle of foodborne illness remains unacceptably thin.

REFERENCES

1. Kilibarda, N. – Brdar, I. – Baltic, B. – Markovic, V. – Mahmutovic, H. – Karabasil, N. – Stanisic, S.: The safety and quality of sous vide food. Meat Technology, *59*, 2018, pp. 38–45. DOI: 10.18485/meattech.2018.59.1.5.
2. Turner, E. R. – Luo, Y. – Buchanan, R. L.: Microgreen nutrition, food safety, and shelf life: A review. Journal of Food Science, *85*, 2020, pp. 870–882. DOI: 10.1111/1750-3841.15049.
3. Kyriacou, M. C. – Rouphael, Y. – Di Gioia, F. – Kyratzis, A. – Serio, F. – Renna, M. – Santamaria, P.: Micro-scale vegetable production and the rise of microgreens. Trends in Food Science and Technology, *57* Part A, 2016, pp. 103–115. DOI: 10.1016/j.tifs.2016.09.005.
4. Singh, A. – Singh, J. – Kaur, S. – Gunjal, M. – Kaur, J. – Nanda, V. – Ullah, R. – Ercisli, S. – Rasane, P.: Emergence of microgreens as a valuable food, current understanding of their market and consumer perception: A review. Food Chemistry: X, *23*, 2024, article 101527. DOI: 10.1016/j.fochx.2024.101527.
5. Xiao, Z. – Lester, G. E. – Luo, Y. – Wang, Q.: Assessment of vitamin and carotenoid concentrations of emerging food products: edible microgreens. Journal of Agricultural and Food Chemistry, *60*, 2012, pp. 7644–7651. DOI: 10.1021/jf300459b.
6. Spence, C. – Okajima, K. – Cheok, A. D. – Petit, O. – Michel, C.: Eating with our eyes: From visual hunger to digital satiation. Brain and Cognition, *110*, 2016, pp. 53–63. DOI: 10.1016/j.bandc.2015.08.006.
7. Chatterjee, S. – Joshi, A.: Micro greens: a new age technique in food presentation and its utilization in the gastronomic world. International Journal of Creative Research Thoughts (IJCRT), 8(5), 2020, pp. 4042–4050. ISSN: 2320-2882. <http://ijcrt.org/viewfull.php?&p_id=IJCRT2005542>
8. Michell, K. A. – Isweiri, H. – Newman, S. E. – Bunning, M. – Bellows, L. L. – Dinges, M. M. – Grabos, L. E. – Rao, S. – Foster, M. T. – Heuberger, A. L. – Prenni, J. E. – Thompson, H. J. – Uchanski, M. E. – Weir, T. L. – Johnson, S. A.: Microgreens: Consumer sensory perception and acceptance of an emerging functional food crop. Journal of Food Science, *85*, 2020, pp. 926–935. DOI: 10.1111/1750-3841.15075.
9. Seth, T. – Mishra, G. P. – Chattopadhyay, A. – Deb Roy, P. – Devi, M. – Sahu, A. – Sarangi, S. K. – Mhatre, C. S. – Lyngdoh, Y. A. – Chandra, V.: Microgreens: Functional food for nutrition and dietary diversification. Plants, *14*, 2025, article 526. DOI: 10.3390/plants14040526.
10. Teng, J. – Liao, P. – Wang, M.: The role of emerging micro-scale vegetables in human diet and health benefits – an updated review based on microgreens. Food and Function, *12*, 2021, pp. 1914–1932. DOI: 10.1039/d0fo03299a.
11. Barańska, D. – Panek, J. – Różalska, S. – Turnau, K. – Frąc, M.: Microgreens as the future of urban horticulture and superfoods, supported by post-harvest innovations for shelf-life increase: A review. Scientia Horticulturae, *350*, 2025, article 114303. DOI: 10.1016/j.scienta.2025.114303.
12. Xavier, I. B. – Tavares, J. L. – Pontes, E. D. S. – Magnani, M. – Alvarenga, V. O.: Understanding food safety on sprouts and microgreens: Contamination routes, outbreaks and challenges. Food Research International, 214, 2025, article 116589. DOI: 10.1016/j.foodres.2025.116589.
13. Riggio, G. M. – Wang, Q. – Kniel, K. E. – Gibson, K. E.: Microgreens – A review of food safety considerations along the farm to fork continuum. International Journal of Food Microbiology, *290*, 2019, pp. 76–85. DOI: 10.1016/j.ijfoodmicro.2018.09.027.
14. Deng, W. – Gibson, K. E.: Microgreen variety impacts leaf surface persistence of a human norovirus surrogate. Food and Environmental Virology, *15*, 2023, pp. 82–88. DOI: 10.1007/s12560-022-09536-x.
15. Chandon, P. – Wansink, B.: The biasing health halos of fast-food restaurant health claims: Lower calorie estimates and higher side-dish consumption intentions. Journal of Consumer Research, *34*, 2007, pp. 301–314. DOI: 10.1086/519499.
16. Sharma, S. – Shree, B. – Sharma, D. – Kumar, S. – Kumar, V. – Sharma, R. – Saini, R.: Vegetable microgreens: The gleam of next generation super foods, their genetic enhancement, health benefits and processing approaches. Food Research International, *155*, 2022, article 111038. DOI: 10.1016/j.foodres.2022.111038.
17. Lobiuc, A. – Vasilache, V. – Oroian, M. – Stoleru, T. – Burducea, M. – Pintilie, O. – Zamfirache, M.-M.: Blue and red LED illumination improves growth and bioactive compounds contents in acyanic and cyanic *Ocimum basilicum* L. microgreens. Molecules, *22*, 2017, article 2111. DOI: 10.3390/molecules22122111.
18. Rihn, A. – Khachatryan, H. – Campbell, B. – Hall, C. – Behe, B.: Consumer preferences for organic production methods and origin promotions on ornamental plants: Evidence from eye-tracking experiments. Agricultural Economics, *47*, 2016, pp. 599–608. DOI: 10.1111/agec.12258.
19. Kyriacou, M. C. – El-Nakhel, C. – Graziani, G. – Pannico, A. – Soteriou, G. A. – Giordano, M. – Ritieni, A. – De Pascale, S. – Rouphael, Y.: Functional quality in novel food sources: Genotypic variation in the nutritive and phytochemical composition of thirteen microgreens species. Food Chemistry, *277*, 2019, pp. 107–118. DOI: 10.1016/j.foodchem.2018.10.098.
20. Caracciolo, F. – El-Nakhel, C. – Raimondo, M. – Kyriacou, M. C. – Cembalo, L. – De Pascale, S. – Rouphael, Y.: Sensory attributes and consumer acceptability of 12 microgreens species. Agronomy, *10*, 2020, article 1043. DOI: 10.3390/agrono-

my10071043.
21. Shamshiri, R. – Kalantari, F. – Ting, K. C. – Thorp, K. R. – Hameed, I. A. – Weltzien, C. – Ahmad, D. – Shad, Z. M.: Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. International Journal of Agricultural and Biological Engineering, *11*, 2018, pp. 1–22. DOI: 10.25165/j.ijabe.20181101.3210.
22. Benke, K. – Tomkins, B.: Future food-production systems: vertical farming and controlled-environment agriculture. Sustainability: Science, Practice and Policy, *13*, 2017, pp. 13–26. DOI: 10.1080/15487733.2017.1394054.
23. Zhang, Y. – Xiao, Z. – Ager, E. – Kong, L. – Tan, L.: Nutritional quality and health benefits of microgreens, a crop of modern agriculture. Journal of Future Foods, *1*, 2021, pp. 58–66. DOI: 10.1016/j.jfutfo.2021.07.001.
24. Cano-Lamadrid, M. – Martínez-Zamora, L. – Castillejo, N. – Cattaneo, C. – Pagliarini, E. – Artés-Hernández, F.: How does the phytochemical composition of sprouts and microgreens from Brassica vegetables affect the sensory profile and consumer acceptability? Postharvest Biology and Technology, *203*, 2023, article 112411. DOI: 10.1016/j.postharvbio.2023.112411.
25. Verlinden, S.: Microgreens: Definitions, product types, and production practices. In: Horticultural Reviews. Hoboken : Wiley, 2019, pp. 85–124. ISBN: 9781119625339. DOI: 10.1002/9781119625407.ch3.
26. Ebert, A. W.: Sprouts and microgreens – Novel food sources for healthy diets. Plants, *11*, 2022, article 571. DOI: 10.3390/plants11040571.
27. Kilibarda, N. – Djokovic, F. – Suzic, R.: Food waste management – reducing and managing food waste in hospitality. Meat Technology, *60*, 2020, pp. 134–142. DOI: 10.18485/meattech.2019.60.2.8.
28. Di Gioia, F. – Renna, M. – Santamaria, P.: Sprouts, microgreens and “baby leaf” vegetables. In: Yildiz, F. – Wiley, R. (Eds.): Minimally processed refrigerated fruits and vegetables. Food Engineering Series. Boston : Springer, 2017, pp. 237–259. ISBN: 978-1-4939-7016-2. DOI: 10.1007/978-1-4939-7018-6_11.
29. Mogren, L. – Windstam, S. – Boqvist, S. – Vågsholm, I. – Söderqvist, K. – Rosberg, A. K. – Lindén, J. – Mulaosmanovic, E. – Karlsson, M. – Uhlig, E. – Håkansson, Å. – Alsanius, B.: The hurdle approach – A holistic concept for controlling food safety risks associated with pathogenic bacterial contamination of leafy green vegetables: A review. Frontiers in Microbiology, *9*, 2018, article 1965. DOI: 10.3389/fmicb.2018.01965.
30. Kilibarda, N.: Food safety and waste in hospitality. In: Leal Filho, W. – Azul, A. M. – Brandli, L. – Özuyar, P. G. – Wall, T. (Eds.): Zero hunger. Encyclopedia of the UN sustainable development goals. Cham: Springer, 2020, pp. 338–347. DOI: 10.1007/978-3-319-95675-6_107.
31. Du, M. – Xiao, Z. – Luo, Y.: Advances and emerging trends in cultivation substrates for growing sprouts and microgreens toward safe and sustainable agriculture. Current Opinion in Food Science, *46*, 2022, article 100863. DOI: 10.1016/j.cofs.2022.100863.
32. Fatima, U. – Senthil-Kumar, M.: Plant and pathogen nutrient acquisition strategies. Frontiers in Plant Science, *6*, 2015, article 750. DOI: 10.3389/fpls.2015.00750.
33. Miyahira, R. F. – Antunes, A. E. C.: Bacteriological safety of sprouts: A brief review. International Journal of Food Microbiology, *352*, 2021, article 109266. DOI: 10.1016/j.ijfoodmicro.2021.109266.
34. Erickson, M. C.: Internalization of fresh produce by foodborne pathogens. Annual Review of Food Science and Technology, *3*, 2012, pp. 283–310. DOI: 10.1146/annurev-food-022811-101211.
35. Xiao, Z. – Bauchan, G. – Nichols-Russell, L. – Luo, Y. – Wang, Q. – Nou, X.: Proliferation of *Escherichia coli* O157:H7 in soil-substitute and hydroponic microgreen production systems. Journal of Food Protection, *78*, 2015, pp. 1785–1790. DOI: 10.4315/0362-028X.JFP-15-063.
36. Paradiso, V. M. – Castellino, M. – Renna, M. – Gattullo, C. E. – Calasso, M. – Terzano, R. – Allegretta, I. – Leoni, B. – Caponio, F. – Santamaria, P.: Nutritional characterization and shelf-life of packaged microgreens. Food and Function, *9*, 2018, pp. 5629–5640. DOI: 10.1039/C8FO01182F.
37. Murphy, C. – Pill, W.: Cultural practices to speed the growth of microgreen arugula (roquette; *Eruca vesicaria* subsp. *sativa*). Journal of Horticultural Science and Biotechnology, *85*, 2010, pp. 171–176. DOI: 10.1080/14620316.2010.11512650.
38. Dubey, S. – Harbourne, N. – Harty, M. – Hurley, D. – Elliott-Kingston, C.: Microgreens production: Exploiting environmental and cultural factors for enhanced agronomical benefits. Plants, *13*, 2024, article 2631. DOI: 10.3390/plants13182631.
39. Morrow, R. C.: LED lighting in horticulture. HortScience, *43*, 2008, pp. 1947–1950. DOI: 10.21273/HORTSCI.43.7.1947.
40. Brazaitytė, A. – Miliauskienė, J. – Vaštakaitė-Kairienė, V. – Sutulienė, R. – Laužikė, K. – Duchovskis, P. – Małek, S.: Effect of different ratios of blue and red LED light on Brassicaceae microgreens under a controlled environment. Plants, *10*, 2021, article 801. DOI: 10.3390/plants10040801.
41. Carvalho, S. D. – Folta, K. M.: Green light control of anthocyanin production in microgreens. ISHS Acta Horticulturae, *1134*, 2016, article 2. DOI: 10.17660/ActaHortic.2016.1134.2.
42. Abaajeh, A. R. – Kingston, C. E. – Harty, M.: Environmental factors influencing the growth and pathogenicity of microgreens bound for the market: A review. Renewable Agriculture and Food Systems, *38*, 2023, article e12. DOI: 10.1017/S174217052300008X.
43. Miyahira, R. F. – Antunes, A. E. C.: Bacteriological safety of sprouts: A brief review. International Journal of Food Microbiology, *352*, 2021, article 109266. DOI: 10.1016/j.ijfoodmicro.2021.109266.
44. Kou, L. – Yang, T. – Luo, Y. – Liu, X. – Huang, L. – Codling, E. E.: Pre-harvest calcium

application increases biomass and delays senescence of broccoli microgreens. Postharvest Biology and Technology, *87*, 2014, pp. 70–78. DOI: 10.1016/j.postharvbio.2013.08.004.

45. Renna, M. – Paradiso, V. M.: Ongoing research on microgreens: Nutritional properties, shelf-life, sustainable production, innovative growing and processing approaches. Foods, *9*, 2020, article 826. DOI: 10.3390/foods9060826.
46. Sobhanan, A. – Meena, R. – Pareek, S. – Meena, B. – Mishra, G. P. – Koley, T. K.: *Aloe vera* gel coating maintains quality and safety and extends shelf life of *Brassica juncea* L. and *Lactuca sativa* L. microgreens. Journal of Food Quality, *2025*, 2025, article 2441276. DOI: 10.1155/jfq/2441276.
47. Zhu, H. – Chen, S. – Xue, J. – Wang, X. – Xiao, Z. – Luo, Y.: Application of nanotechnology in sprouts and microgreens: Current developments and future perspectives. Journal of Agriculture and Food Research, *19*, 2025, article 101680. DOI: 10.1016/j.jafr.2025.101680.
48. Gunjal, M. – Singh, J. – Kaur, J. – Kaur, S. – Nanda, V. – Sharma, A. – Rasane, P.: Microgreens: Cultivation practices, bioactive potential, health benefits, and opportunities for its utilization as value-added food. Food Bioscience, *62*, 2024, article 105133. DOI: 10.1016/j.fbio.2024.105133.
49. Wheeler, R. M.: Agriculture for space: People and places paving the way. Open Agriculture, *1*, 2017, pp. 14–32. DOI: 10.1515/opag-2017-0002.
50. Soumya, S. L. – Raj, S. – Anees, K. – Sankar, S. M. – Job, J. T. – Narayanankutty, A. – Sebastian, D. P. – George, S.: Compositional and nutritional assessment of seed spice microgreens for functional food applications. Journal of Food Composition and Analysis, *149*, 2026, article 108830. DOI: 10.1016/j.jfca.2025.108830.
51. Weber, C. F.: Broccoli microgreens: A mineral-rich crop that can diversify food systems. Frontiers in Nutrition, *4*, 2017, article 7. DOI: 10.3389/fnut.2017.00007.
52. Pinto, E. – Almeida, A. A. – Aguiar, A. A. – Ferreira, I. M. P. L. V. O.: Comparison between the mineral profile and nitrate content of microgreens and mature lettuces. Journal of Food Composition and Analysis, *37*, 2015, pp. 38–43. DOI: 10.1016/j.jfca.2014.06.018.
53. Gunathilake, S. – Aluthge, S. – Farahnaky, A. – Jafarzadeh, S. – Majzoobi, M.: Cereal and pseudocereal microgreens: Emerging functional foods for human health and sustainability. Journal of Cereal Science, *125*, 2025, article 104259. DOI: 10.1016/j.jcs.2025.104259.
54. Germ, M. – Stibilj, V. – Šircelj, H. – Jerše, A. – Kroflič, A. – Golob, A. – Maršić, N. K.: Biofortification of common buckwheat microgreens and seeds with different forms of selenium and iodine. Journal of the Science of Food and Agriculture, *99*, 2019, pp. 4353–4362. DOI: 10.1002/jsfa.9669.
55. Partap, M. – Sharma, D. – Hn, D. – Thakur, M. – Verma, V. – Ujala – Bhargava, B.: Microgreen: A tiny plant with superfood potential. Journal of Functional Foods, *107*, 2023, article 105697. DOI: 10.1016/j.jff.2023.105697.
56. Rawat, M. – Kumar, A. – Kumar, S. – Kaur, R.: Unlocking the potential of microgreens: non-thermal innovations to enhance phytochemical and nutritional benefits. Food Chemistry: X, *29*, 2025, article 102747. DOI: 10.1016/j.fochx.2025.102747.
57. Bhaswant, M. – Shanmugam, D. K. – Miyazawa, T. – Abe, C. – Miyazawa, T.: Microgreens – A comprehensive review of bioactive molecules and health benefits. Molecules, *28*, 2023, article 867. DOI: 10.3390/molecules28020867.
58. Huang, H. – Jiang, X. – Xiao, Z. – Yu, L. – Pham, Q. – Sun, J. – Chen, P. – Yokoyama, W. – Yu, L. L. – Luo, Y. S. – Wang, T. T.: Red cabbage microgreens lower circulating low-density lipoprotein (LDL), liver cholesterol, and inflammatory cytokines in mice fed a high-fat diet. Journal of Agricultural and Food Chemistry, *64*, 2016, pp. 9161–9171. DOI: 10.1021/acs.jafc.6b03805.
59. Samuolienė, G. – Viršilė, A. – Brazaitytė, A. – Jankauskienė, J. – Sakalauskienė, S. – Vaštakaitė, V. – Novičkovas, A. – Viškelienė, A. – Sasnauskas, A. – Duchovskis, P.: Blue light dosage affects carotenoids and tocopherols in microgreens. Food Chemistry, *228*, 2017, pp. 50–56. DOI: 10.1016/j.foodchem.2017.01.144.
60. Rao, I. P. – Pradhan, A. K. – Patel, J.: Persistence of foodborne bacterial pathogens on microgreens and soil irrigated with contaminated water. Journal of Food Protection, *88*, 2025, article 100594. DOI: 10.1016/j.jfp.2025.100594.
61. Chatziprodromidou, I. P. – Bellou, M. – Vantarakis, G. – Vantarakis, A.: Viral outbreaks linked to fresh produce consumption: A systematic review. Journal of Applied Microbiology, *124*, 2018, pp. 932–942. DOI: 10.1111/jam.13747.
62. Warriner, K. – Spaniolas, S. – Dickinson, M. – Wright, C. – Waites, W. M.: Internalization of bioluminescent *Escherichia coli* and *Salmonella* Montevideo in growing bean sprouts. Journal of Applied Microbiology, *95*, 2003, pp. 719–727. DOI: 10.1046/j.1365-2672.2003.02037.x.
63. Deng, W. – Gibson, K. E.: Persistence and transfer of Tulane virus in a microgreen cultivation system. International Journal of Food Microbiology, *387*, 2023, article 110063. DOI: 10.1016/j.ijfoodmicro.2022.110063.
64. Işık, S. – Sülük, K. – Moreira, J. – Topalcengiz, Z.: Assessment of vermicompost compositions containing cattle, sheep, and poultry manures for contamination risk of microgreens by foodborne pathogens. Food Microbiology, *132*, 2025, article 104842. DOI: 10.1016/j.fm.2025.104842.
65. Chen, C.-H. – Yin, H.-B. – Patel, J.: Influence of contamination source and cultivation matrix on survival of *Escherichia coli* O157:H7 and *Salmonella enterica* on daikon microgreens. LWT – Food Science and Technology, *185*, 2023, article 115165. DOI: 10.1016/j.lwt.2023.115165.
66. Rao, A. P. – Pradhan, A. K. – Patel, J.: Transfer of *Salmonella enterica, Escherichia coli* O157:H7

and *Listeria monocytogenes* to microgreens and soil from contaminated seeds. Journal of Agriculture and Food Research, *21*, 2025, article 101761. DOI: 10.1016/j.jafr.2025.101761.

67. Liu, X. – Yao, H. – Zhao, X. – Ge, C.: Biofilm formation and control of foodborn pathogenic bacteria. Molecules, *28*, 2023, article 2432. DOI: 10.3390/molecules28062432.
68. Hung, N. B. – Park, W. R. – Yun, B. – Seo, D. C. – Kim, W.-I. – Kim, H.-J. – Han, S. – Kim, S.-R.: Effect of sequential presoaking and chlorine dioxide treatment on the inactivation of pathogenic *Escherichia coli* and *Salmonella* spp. on sprout seeds. Applied Biological Chemistry, *63*, 2020, article 53. DOI: 10.1186/s13765-020-00537-7.
69. Liu, H. – Zhang, X. – Cui, Z. – Ding, Y. – Zhou, L. – Zhao, X.: Cold plasma effects on the nutrients and microbiological quality of sprouts. Food Research International, *159*, 2022, article 111655. DOI: 10.1016/j.foodres.2022.111655.
70. Hamilton, A. N. – Fraser, A. M. – Gibson, K. E.: Barriers to implementing risk management practices in microgreens growing operations in the United States: Thematic analysis of interviews and survey data. Food Control, *152*, 2023, article 109836. DOI: 10.1016/j.foodcont.2023.109836.
71. Ocho Bernal, T. G. – Lyttle, N. – Jung, Y.: Microbiological quality of microgreen seeds purchased from online vendors and evaluating seed decontamination techniques available online. Frontiers in Sustainable Food Systems, *7*, 2023, article 1264472. DOI: 10.3389/fsufs.2023.1264472.
72. Kilibarda, N. – Karabasil, N. – Grbić, S. – Borovčanin, D. – Đoković, F.: Poslovanje hranom u ugostiteljstvu u skladu sa principima dobre prakse i sistema analize opasnosti i kritičnih kontrolnih tačaka. (Food business in hospitality in accordance with the principles of good practice and the hazard analysis and critical control points system.) Veterinarski zhurnal Republike Srpske, *20*, 2020, pp. 21–35. DOI: 10.7251/VETJSR2001021K. In Serbian.
73. Borovčanin, D. – Kilibarda, N.: Assuring good food handling practices in hospitality, financial costs and employees' attitudes: A case study from Serbia. Meat Technology, *61*, 2020, pp. 82–94. DOI: 10.18485/meattech.2020.61.1.8.
74. Madara, W. P. – Weerawardhana, M. – Haily Seneviratne, R. A. C.: Microgreens as superfoods: How the inclusion of mustard, mung, and radish microgreens influences the nutritional, functional, and sensory properties of a selected salad dish. International Journal of Gastronomy and Food Science, *40*, 2025, article 101139. DOI: 10.1016/j.ijgfs.2025.101139.
75. The European Union One Health 2022 Zoonoses Report. EFSA Journal, *21*, 2023, article e8442. DOI: 10.2903/j.efsa.2023.8442.
76. Czarniecka-Skubina, E. – Trafiałek, J. – Wiatrowski, M. – Głuchowski, A.: An evaluation of the hygiene practices of European street food vendors and a preliminary estimation of food safety for consumers, conducted in Paris. Journal of Food Protection, *81*, 2018, pp. 1614–1621. DOI: 10.4315/0362-028X.JFP-18-165.
77. 21 CFR Parts 11, 16, and 112 [Docket No. FDA–2011–N–0921]. RIN 0910–AG35. Standards for the growing, harvesting, packing, and holding of produce for human consumption. Federal Register – The Daily Journal of the United States Government, *80*, 2015, No. 228, 27 November 2015, pp. 74354–74568. <https://www.federalregister.gov/d/2015-28159>
78. FDA-2017-D-0175. Guidance for industry: standards for the growing, harvesting, packing, and holding of sprouts for human consumption. In: U.S. Food and Drug Administration [online]. Silver Spring : Food and Drug Administration, 28 September 2023 [cited 16 March 2026]. <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-standards-growing-harvesting-packing-and-holding-sprouts-human-consumption>
79. Scientific Opinion on the risk posed by Shiga toxin-producing *Escherichia coli* (STEC) and other pathogenic bacteria in seeds and sprouted seeds. EFSA Journal, *9*, 2011, article 2424. DOI: 10.2903/j.efsa.2011.2424.

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