

Multipurpose Biodegradable Fiber Mats and Mulch Sheets in Agriculture: Applications in Microgreen Production and Weed Suppression

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ABSTRACT

Global food systems currently face critical pressures from population growth and shrinking agricultural resources, necessitating a transition toward nutrient-dense and spatially efficient production models. Microgreens have emerged as a promising solution; however, their sustainability is largely dependent on the choice of growing media. This review synthesises the biological and systemic requirements of microgreen cultivation with a particular focus on the transition from traditional soil and synthetic substrates to biodegradable natural fiber mats derived from hemp, jute, coconut coir, and agricultural byproducts. The analysis explores the comparative agronomic performance, operational advantages, and environmental impacts of these bio-based media. Furthermore, it evaluates the dual-application potential of these fibers as field-scale mulch sheets for weed suppression, highlighting their role in reducing reliance on synthetic herbicides and plastic films. By integrating diverse biomass sources such as rice husks and water hyacinth into a circular-economy framework, these biodegradable materials support a resilient, low-carbon food production lifecycle accessible to both commercial and household-scale growers.

Keywords: Agriculture, Microgreen, Weed Suppression and Biodegradable.

Introduction

Modern food systems are under immense strain as they attempt to balance a growing global population with a shrinking base of natural resources. With the United Nations forecasting a population of 10 billion by mid-century, the urgency to produce high volumes of nutrient-dense crops has never been higher [1]. However, traditional agriculture is losing ground literally to urban sprawl, soil exhaustion, and increasing salinity [2]. This crisis of scale has already left nearly 2.4 billion people struggling with food insecurity, often lacking the vital micronutrients necessary for basic health according to the UN report in the year 2019. Furthermore, the financial burden of modern food logistics makes high-quality nutrition increasingly inaccessible for many global communities [3].

To address these systemic vulnerabilities, researchers are shifting focus toward production models that prioritize nutrient density and spatial economy over traditional land-intensive farming. Microgreens seedlings harvested just as their first leaves emerge have become a focal point of this shift. These young plants offer a rapid harvest cycle of roughly one to two weeks and can be cultivated anywhere from urban apartments to industrial-scale vertical farms [4,5]. Beyond their convenience, microgreens are nutritional powerhouses; studies show they frequently exceed their mature counterparts in concentrations of vitamins C, E, and K, as well as essential antioxidants and carotenoids [4,6,7].

Their culinary flexibility, ranging from sweet to sharp flavor profiles, further enhances their appeal for both daily diets and specialized health supplements [8,9].

The long-term viability of microgreen cultivation depends largely on the choice of growing media. While soil is the traditional default, it often introduces unwanted pathogens or weeds into controlled environments [10]. Conversely, while effective, synthetic options like rockwool contribute to the growing problem of non-biodegradable agricultural waste [2,12]. This has led to a surge in interest in biodegradable fiber mats. Utilizing materials such as hemp, jute, or coconut coir allows growers to maintain high standards of aeration and water retention while ensuring the entire system remains compostable and environmentally neutral [13,14,15,16].

In addition to their role in seedling production, these same natural fibers can be engineered via compression or composite blending into durable mulch sheets for large-scale field use. Weeds remain a premier economic hurdle for global farmers, often outcompeting crops for essential sunlight and moisture [2, 17]. While herbicides are a common fix, they bring significant risks involving chemical runoff, public health, and tightening legal regulations. Biodegradable mulch sheets provide a cleaner, less labour intensive alternative; they physically block weed growth and eventually break down to improve soil structure and nutrient content [16, 17, 19].

This review serves several objectives: (i) to detail the biological and systemic requirements of microgreen cultivation; (ii) to analyze available growing substrates, specifically focusing on

natural fiber mats; (iii) to weigh the performance and practical limitations of these biodegradable options; (iv) to examine the dual-purpose potential of fibers as both growth media and weed-suppressing mulch; and (v) to evaluate the economic trajectory and future potential of bio-based agricultural tools. Collectively, these topics highlight how biodegradable fibers support a circular economy and advance sustainable farming practices.

2. Overview of Microgreen Production

Microgreens are characterized as immature vegetable greens typically gathered between 7 and 14 days following germination. They are generally harvested once they reach the cotyledon or initial true-leaf phase, standing at a height of roughly 25 to 38 mm. This edible biomass consists of the tender central stem and the first pair of seed leaves (cotyledons), sometimes including the very early true leaves. If growth continues past this specific developmental window, the plants transition into "petite greens" and are no longer categorized as microgreens.

Table 1: Commonly Cultivated Microgreen Species, Taxonomy, and Key Attributes

S.No	Common Name	Scientific Name	Key Nutritional / Culinary Attributes
I.	Family: Brassicaceae		
1	Broccoli	<i>Brassica oleracea var. italica</i>	Rich in sulforaphane, glucosinolates, vitamin C, and beta-carotene
2	Kale	<i>Brassica oleracea var. sabellica</i>	High in vitamins K, C, calcium, and antioxidants
3	Cabbage	<i>Brassica oleracea var. capitata</i>	Mild flavor; source of vitamin C and dietary fiber
4	Radish	<i>Raphanus sativus</i>	Spicy flavor; high in anthocyanins and ascorbic acid
5	Mustard	<i>Brassica juncea</i>	Peppery taste; rich in phenolics and isothiocyanates
II.	Family: Leguminosae		
1	Peas	<i>Pisum sativum</i>	Sweet flavor; high protein, vitamins A, C, K
2	Sunflower	<i>Helianthus annuus</i>	Nutty, crunchy; elevated vitamin E and healthy lipids
3	Lentils	<i>Lens culinaris</i>	High protein, iron, folate, vitamins B1 and B6
4	Chickpeas	<i>Cicer arietinum</i>	Good source of protein, dietary fiber, and folate
5	Alfalfa	<i>Medicago sativa</i>	Nutrient-rich; supports digestive and immune health
III.	Family: Amaranthaceae / Asteraceae / Lamiaceae		
1	Basil	<i>Ocimum basilicum</i>	Aromatic; rich in vitamin K, flavonoids, and eugenol
2	Spinach	<i>Spinacia oleracea</i>	High in iron, folate, vitamins A and C
3	Beetroot	<i>Beta vulgaris</i>	Earthy and sweet; elevated betalain pigments and nitrates
4	Amaranthus	<i>Amaranthus spp.</i>	High protein and lysine; sweet nutty taste
5	Lettuce	<i>Lactuca sativa</i>	Mild flavor; source of vitamins A and K
IV.	Family: Gramineae		
1	Buckwheat	<i>Fagopyrum esculentum</i>	Mild nutty; rich in rutin, quercetin, antioxidants
2	Barley	<i>Hordeum vulgare</i>	Rich in beta-glucan, vitamins, minerals
3	Corn	<i>Zea mays</i>	Sweet; provides vitamins, dietary fiber, and energy

Source: [8, 18, 20]

Nutritional Profile and Post-Harvest Retention

The scientific consensus heavily favors the nutritional density of microgreens compared to fully grown vegetables. Research by Xiao and coworkers [4] in 2012 highlighted that the cotyledon leaves of these seedlings possess remarkably higher levels of beta-carotene and vitamins C, E, and K than their mature counterparts. This phenomenon is largely driven by the intense mobilization of seed-stored energy and the onset of early photosynthesis [20]. When compared to sprouts, microgreens typically demonstrate a more robust profile of total antioxidants and polyphenols [21]. These bioactive components including chlorophylls, glucosinolates, and organic acids are increasingly recognized for their capacity to mitigate chronic inflammation and oxidative stress [7, 22].

However, maintaining this nutritional wealth after harvest is a significant challenge. Bibliometric data suggests that post-harvest factors namely humidity, packaging environments, and ambient temperature are the primary determinants of how well vitamins and phenols are preserved [23].

It is important to distinguish them from sprouts, which have a much shorter 2-to-7-day growth cycle and are consumed entirely, including the roots and seeds.

2.1 Taxonomy of Microgreen Species

A wide variety of plant families are utilized in microgreen production (Table.1). Common taxonomic groups include Brassicaceae, Leguminosae, Amaranthaceae, Asteraceae, Lamiaceae, and Gramineae

- **Brassicaceae:** Species such as radish, broccoli, and mustard are frequently cultivated due to their high concentrations of antioxidants, sulforaphane, and glucosinolates.
- **Leguminosae:** Microgreens from this family including alfalfa, chickpeas, lentils, and peas are valued for their robust amino acid profiles and high protein content.
- **Other Families:** Families like Amaranthaceae (e.g., amaranth, beets) and Asteraceae (e.g., lettuce, chicory) contribute diverse colors, textures, and nutrient profiles to the market.

Antioxidant activity tends to degrade over time once the plants are cut, making a reliable cold-chain system essential for quality control [24]. Interestingly, nutritional value can also be "pre-programmed" during growth; for instance, manipulating light spectra has been shown to boost flavonoid levels in crops like soybean microgreens [25].

Practical Benefits and Urban Food Security

Beyond their health benefits, microgreens offer unique logistical advantages. Their short production window of one to three weeks facilitates frequent, high-turnover harvesting [5, 26]. Their spatial footprint is incredibly small, allowing for cultivation in diverse settings—from simple kitchen windowsills to advanced, multi-tier vertical farming systems [27, 28]. Because they can be grown indoors under LED lighting, seasonal weather patterns do not restrict production [28].

From a socioeconomic standpoint, microgreens serve as an accessible tool for improving food security.

Low-income households can produce high-quality nutrition with very little initial capital for media or seeds [25,29]. Furthermore, localized "countertop-to-table" cultivation cuts down on the carbon footprint and plastic waste typically linked to the commercial produce supply chain [30,31].

3. Growing Media for Microgreen Production

3.1 Soil-Based Substrates

Soil is the most traditional growing medium for microgreens, providing organic matter, mineral nutrients, and a diverse microbial community that supports plant health. The physical properties of soil namely water retention, aeration, and drainage create a naturally balanced root environment. However, soil-based production carries inherent risks including the introduction of soilborne pathogens, fungal diseases, and weed seeds that can contaminate the harvested product [10]. The weight and messiness of soil present additional practical challenges in indoor and small-scale controlled environments. To minimize these risks, sterilized or pasteurized seed-starting potting mixes with optimized pH (5.5–6.5), low electrical conductivity, and good drainage are strongly recommended for microgreen production [10,32].

Di Gioia and coworkers conducted a comprehensive physicochemical, agronomical, and microbiological evaluation of growing media for microgreens, comparing soil-based substrates with soilless alternatives [10]. Their findings indicated that while soil supports comparable yields to soilless systems, the microbiological contamination risk is significantly higher in soil, a critical concern for fresh, ready-to-eat produce such as microgreens. Islam and his coworkers [33] further demonstrated that the specific formulation of soilless growing media significantly influences microgreen growth, yield, and biochemical composition, confirming that substrate selection is a key quality determinant.

3.2 Soilless Cultivation Methods

Soilless systems have become the preferred choice for microgreen production due to their cleanliness, versatility, and ease of integration into controlled environments [10,32]. Growers utilize a variety of porous materials such as hemp mats, coconut coir, rockwool, peat moss, and burlap to provide essential root anchorage and moisture retention [10,34]. Irrigation can be applied via top-misting or bottom-wicking; the latter is often preferred as it keeps the foliage dry, reducing disease risk and ensuring a cleaner harvest.

Research by El-Nakhel and his coworkers [32] confirms that the choice of substrate is a primary quality driver, significantly affecting plant morphology as well as the concentration of antioxidants and minerals. This shift toward sustainable media is also reflected in the commercial market, where eco-friendly kits featuring organic seeds and cocopeat have seen high consumer demand [20].

3.2.1 Aeroponic Systems

Aeroponics is a high-tech soilless method where roots are suspended in air and periodically sprayed with a fine nutrient mist (10–100 μm droplets). This setup provides maximum oxygen exposure to the roots and uses water with extreme efficiency, making it ideal for urban or water-scarce regions [36, 37]. While purpose-built aeroponic towers can maximize early growth and germination, the system requires significant upfront investment and technical oversight; even brief power or pump failures can lead to immediate crop loss [35,37].

3.2.2 Hydroponic Substrates

Hydroponics remains the most popular commercial framework for microgreen production [10]. Plants typically grow on thin capillary mats or pads made of jute, hemp, or coconut coir, which are kept moist by a nutrient-rich water solution. For budget-conscious or small-scale setups, materials like burlap or even paper towels can serve as effective substitutes [34].

Commonly used techniques include Deep Water Culture (DWC) and Nutrient Film Technique (NFT). In DWC, plants float on a substrate while roots extend into an aerated solution. Maintaining the right level of dissolved oxygen is vital; too little leads to root hypoxia and pathogens, while too much can physically stress the delicate root structures [33,38].

Hydroponic systems also allow for precise "nutritional tailoring." For example, supplementing the water with iron chelates can significantly boost the mineral content of the greens [12]. Additionally, simple techniques like pre-soaking seeds can elevate bioactive phytochemical levels without increasing costs [33]. Studies comparing materials like jute and peat show that natural fibers can match the yields of traditional substrates while offering the added benefit of complete biodegradability [14,39].

3.2.3 Aquaponic Systems

Aquaponics combines fish farming with hydroponics to create a closed-loop, recirculating ecosystem. In this setup, nitrifying bacteria convert fish waste into accessible nitrogen for plants; the plants, in turn, act as a biological filter that cleans the water before it returns to the fish (Nicoletto et al., 2018). This symbiotic relationship is incredibly efficient, often recycling over 95% of the system's water [40,41]. Beyond resource conservation, aquaponics may even stimulate growth by improving nutrient uptake and providing natural biocontrol against root diseases.

While traditionally used for larger crops like tomatoes, research suggests that aquaponic systems are highly competitive with standard hydroponics in terms of yield and waste reduction [36]. Integrating fast-growing, high-value crops like microgreens into these systems is a logical evolution for urban agriculture, offering a dual-harvest model of both protein and nutrient-dense greens [40,41].

3.3 Natural Fiber-Based Growing Media

The use of natural fiber substrates derived from hemp, jute, coconut coir, rice straw, banana fiber, or sisal represents a shift toward truly sustainable cultivation [13, 15]. These materials are processed into mats that facilitate germination and are entirely compostable. Upon disposal, they break down into the soil, replenishing it with organic matter and micronutrients while supporting beneficial microbial life [12,13,15]. Their ability to hold moisture for three to four days makes them particularly effective for low-maintenance setups like community gardens or home-scale urban farming [15].

Recent studies have underscored the viability of these materials. Mitra and coworkers [15] detailed how natural fiber mats perform relative to traditional substrates in terms of root penetration and water retention. Similarly, evaluations of cocopeat and other agricultural residues have shown that these bio-based media can actually improve the yield and antioxidant levels of crops like beet microgreens compared to conventional options [42,43].

4. Categories of Biodegradable Grow Mats

4.1 Hemp Fiber Mats

Hemp (*Cannabis sativa L.*) is increasingly viewed as a premier material for microgreen substrates, thanks to its high mechanical durability, impressive water retention, and sustainable profile. With a near-neutral pH of roughly 6.7, hemp is perfectly suited for most hydroponic microgreens. It can absorb up to 1,000% of its dry weight in water, ensuring a stable, moist environment for rapid germination and healthy root expansion [15]. While hemp is often grown for seeds or oils, the tough outer bast fiber traditionally a secondary byproduct makes an ideal raw material for grow mats. These fibers are entirely compostable and possess a tensile strength that rivals some synthetics while remaining 100% renewable.

Unlike some materials that collapse when saturated, hemp mats maintain their structural integrity, preserving the essential airflow needed at the root zone [34]. Additionally, hemp's low water requirements and minimal need for chemical inputs further bolster its status as an eco-friendly choice [15].

4.2 Jute Fiber Mats

Jute (*Corchorus* species) mats, often referred to as felt or geotextile pads, are created by needle-punching fibers into a dense, manageable fabric [14]. These have seen widespread commercial use in vertical farms due to their rigidity and ability to distribute moisture evenly. Being organic and biodegradable, jute poses no risk of chemical leaching into the food supply.

The needle-punched texture of these mats acts as a thermal buffer and moisture reservoir. They hold enough water at the seed level for germination while allowing excess liquid to drain, which prevents root rot [39]. Studies show that microgreens grown on jute perform as well as those in traditional peat, with the added benefit of being fully compostable [39, 44].

In practice, jute mats require a brief pre-soak in warm water to overcome initial dryness. Once seeds are sown and germinated in the dark, the trays are moved to light, where the mats' capillary action allows for efficient bottom-watering. This method ensures the final product is clean and free of soil residue [20].

4.3 Coconut Coir Mats

Derived from coconut husks, coir consists of two fiber types: tough brown fibers from mature fruit and softer white fibers from younger fruit [15]. While coir has been used in gardening for over a century, it has recently surged in popularity as a sustainable, high-performance alternative to peat [42].

Coco coir can hold 400–600% of its weight in water while maintaining the porosity necessary for oxygen to reach the roots [13]. Its pH range (5.5–6.8) and low salinity allow growers to maintain precise control over nutrient levels. When compressed and needle-punched into mats, coir becomes a structured, easy-to-handle substrate. Research indicates that coir-based media can actually enhance the antioxidant and nutritional levels of microgreens compared to soil [42].

While coir mats are easy to use and compostable, they are typically single-use and can dry out faster than peat in low-humidity settings. They also usually require supplemental nutrients to support growth beyond the very earliest stages [10]. Nevertheless, coir remains one of the most scientifically backed and commercially successful natural fiber substrates globally [13].

4.4 Emerging Natural Fiber Alternatives

Beyond the leading commercial options, several innovative substrates derived from agricultural waste are being explored. Rice straw, an abundant global byproduct, is a prime candidate due to its high silica content and structural stiffness, especially in major rice-growing regions [2]. Similarly, fibers from banana pseudostems another common plantation waste provide effective biodegradability and moisture retention.

Environmental challenges are also being turned into agricultural assets; for instance, the invasive aquatic weed water hyacinth (*Eichhornia crassipes*) is being processed into composite mats to repurpose it as a functional resource. Research into these diverse plant residues suggests they can successfully enhance the quality and yield of crops like beet microgreens, proving that various agricultural side-streams have significant potential as sustainable growth media [38].

5. Benefits of Using Biodegradable Grow Mats

Biodegradable mats provide a variety of agronomic, functional, and ecological benefits, positioning them as superior alternatives to traditional growing media (Table 2).

Agronomic Performance

Specific fiber-based substrates have been shown to improve the absorption of vital minerals like nitrogen, potassium, phosphorus, iron, and zinc, thereby boosting the overall nutritional profile of the crop. Research indicates that microgreens grown on these mats achieve yields and sensory qualities such as texture and flavor that are on par with traditional peat-based systems [32]. Furthermore, the precise nutrient control offered by these mats makes them ideal for specialized techniques like biofortification; for example, successfully enriching basil microgreens with selenium to enhance their nutraceutical value [21].

Operational Advantages

From a logistical standpoint, fiber mats are lightweight and flexible, which simplifies setup and reduces labor costs [20]. The absence of soil ensures that the harvested greens are free of grit and debris, cutting down on the time and water required for postharvest cleaning. Additionally, selling microgreens as "living products" with the mat still attached can significantly extend their shelf life and reduce waste [10]. The flat surface of the mat also allows for more uniform seed spacing, leading to consistent growth and higher product quality [15].

Environmental Impact

Unlike synthetic pads that contribute to plastic pollution, natural fiber mats are fully compostable and return nutrients to the soil [2, 11]. Because they are derived from renewable agricultural materials, they possess a much lower carbon footprint throughout their lifecycle [25]. Shifting to these mats also helps protect fragile peatland ecosystems, which are often destroyed by traditional substrate extraction [17]. Finally, by eliminating the need for soil, these systems naturally bypass soilborne pathogens, reducing the reliance on chemical treatments and ensuring a safer food product [10].

6. Limitations and Practical Challenges

While biodegradable mats offer significant benefits, scaling their use involves overcoming several technical, economic, and logistical hurdles.

Moisture and Oxygen Balance

Achieving the correct hydration level is a delicate balance; mats must stay damp enough for germination without becoming waterlogged, which would starve roots of oxygen and invite pathogens. Certain materials, such as thin cotton or jute, have lower water retention than peat, requiring more frequent irrigation and oversight [10,15]. In systems like Deep Water Culture (DWC), the top of the mat can dry out even as the roots reach the water, making consistent water-level management essential.

Environmental Sensitivity

Microgreens grown on fiber mats are highly reactive to their surroundings. Factors like CO₂ levels, humidity, light intensity, and temperature must be strictly regulated to ensure high yields and nutrient density [28]. While commercial farms use automated systems to manage these variables, home growers or low-tech operations may struggle with inconsistent germination or lower nutritional quality due to environmental fluctuations [33].

Precision in Nutrient Delivery

Because microgreens transition quickly from using seed energy to absorbing external nutrients, the irrigation solution must be expertly calibrated. Both nutrient deficiencies and toxic buildup can occur if fertigation is not precisely managed [18].

Table 2: Properties of Key Growing Media

Parameter	Soil	Peat Moss	Synthetic Pads	Biodegradable Mats
Reusability	Limited	Limited	Some	No
Biodegradability	Yes	Yes	No	Yes
Pathogen Risk	High	Moderate	Low	Low
Water Retention	Good	Excellent	Variable	Good- excellent
Aeration	Moderate	Moderate	Variable	Good
Cleanliness	Low	Low	High	High
Plastic Waste	None	None	High	None
Eco-Impact	Moderate	High (Depletion)	High	Low
Cost	Low	Moderate	Moderate	Moderate-High

8. Sustainability and Environmental Lifecycle

Natural fiber mats advance a circular economy by repurposing agricultural "waste" such as coconut husks, jute stalks, and rice straw into high-value growing tools [45]. This process minimizes net agricultural waste and reduces reliance on petroleum-based products. Life-cycle assessments indicate that biodegradable alternatives carry a much lighter environmental burden, provided local composting infrastructure is available to manage the spent material [46]. Innovation in this space has even led to "active" mulch films made from hydrolyzed fruit peels and biochar, which further enrich the soil as they degrade [48].

9. Fiber-Based Mulch Sheets for Weed Management

Weeds are a primary economic threat to global farming, capable of slashing yields by up to 80% [2]. While herbicides are effective, their use is increasingly restricted due to environmental and health concerns. Physical barriers, or mulch sheets, offer a low-labor alternative.

While synthetic polyethylene films are common, they create a massive plastic pollution crisis. In contrast, biodegradable fiber sheets often made from jute, hemp, or PLA blends provide early-season weed control and break down naturally into the soil [19]. These "green" production methods prove that petroleum-free films can effectively compete with traditional plastics in commercial agriculture [25].

Research confirms that even minor adjustments such as targeted micronutrient additions or pre-sowing seed treatments can drastically change the plant's final mineral and phytochemical makeup [12,33].

Economic and Logistical Barriers

The initial cost of biodegradable mats is typically higher than that of soil, which can be a barrier for small-scale or subsistence growers. Additionally, natural fibers are susceptible to environmental degradation before they are even used; in humid or tropical regions, improper storage can lead to mold growth and material breakdown [15]. Finally, the availability of specific fibers like hemp or jute depends on regional supply chains, which may limit their use in certain parts of the world.

7. Comparative Assessment of Growing Media

The choice of substrate fundamentally dictates the environmental and operational footprint of microgreen production. As shown in **Table 2**, traditional soil and peat offer familiarity but come with significant drawbacks, such as high pathogen risks or the ecological destruction of peatland carbon sinks [17]. Transitioning to biodegradable natural fiber mats represents a "climate-positive" evolution, matching the yield of peat while eliminating the plastic waste associated with synthetic pads [47].

9.1 Rice Husk Mats for Targeted Suppression

Rice husks, high in silica and structural rigidity, are being engineered into rigid mulch mats to control specific invasive weeds like goosegrass. Research indicates that mat thickness is the most critical factor for success; for instance, while 2mm or 4mm mats allow enough light for weeds to germinate, an 8mm mat effectively blocks light transmission, preventing weed emergence entirely [49].

9.2 Composite Mulch Mats

Water hyacinth, rice straw, and banana pseudo stems are globally abundant biomass sources that often pose disposal challenges. Transforming these into composite mulch sheets addresses waste management while providing an effective tool for weed suppression [43]. Research by Iriany and coworkers [11] into various blending ratios revealed that a mix of 60% water hyacinth, 20% rice straw, and 20% banana pseudostem yielded the highest tensile strength and organic carbon content. This specific formulation offers the structural durability necessary for field use while providing the most significant boost to soil organic matter as it decays. These findings prove that blending different fibers can create a superior product compared to single-fiber mats, offering a low-cost, fully biodegradable alternative to plastic.

10. Industry Trends and Commercial Outlook

The rapid growth of vertical farming and Controlled Environment Agriculture (CEA) is driving a surge in demand for high-performance, sustainable substrates. With the vertical farming market projected for double-digit growth through 2030, operators are increasingly choosing biodegradable media to meet corporate sustainability goals and consumer expectations [30]. Economic analyses show that when paired with optimized LED lighting, these substrates enhance the financial viability of indoor farming [28].

Natural fiber mats made from hemp, jute, and coir are already staples in commercial facilities across North America, Europe, and Asia [13]. Simultaneously, the rise of home-growing kits has opened a significant direct-to-consumer market [45]. Beyond production, these soilless systems are being recognized for their role in community food security and urban resilience [27, 50].

In the field-scale segment, tightening regulations on single-use plastics particularly in the EU and UK are forcing a shift away from polyethylene films [17]. This regulatory pressure, combined with advances in fiber processing, has positioned biodegradable mulch sheets for major market expansion as they become a core component of environmentally responsible modern agriculture.

11. Impact on Global Nutrition and Food Security

Adopting biodegradable fiber mats in microgreen cultivation directly supports global efforts to improve nutritional security. The High Level Panel of Experts (HLPE, 2020) has noted that systemic food transformation requires innovations that boost nutrient density while remaining environmentally sustainable. Microgreens grown on bio-based mats fulfill these criteria by providing a low-cost, high-impact nutrition source [31].

Modeling by Springmann and coworkers [51] suggests that diets centred on nutrient-dense plant foods are both healthier and more ecologically viable than current global averages. Because these fiber mats require minimal infrastructure, they enable low-income urban and peri-urban populations to produce their own fresh produce, bypassing the economic and seasonal barriers of traditional supply chains [13,25]. Furthermore, hands-on cultivation using these kits has been shown to improve nutritional literacy and dietary attitudes, serving as an effective educational tool [52]. Beyond basic calories, the precision of soilless systems allows for the biofortification of microgreens with essential minerals like zinc and selenium. This capability offers a powerful, affordable strategy for addressing specific micronutrient deficiencies at a household scale [22,34].

12. Conclusion

Biodegradable fiber mats and mulch sheets have emerged as a mature, agronomically sound, and ecologically superior class of agricultural tools. As a growing medium, fibers from hemp, jute, and coconut coir match the performance of synthetic alternatives while ensuring that the system remains fully compostable and free of plastic waste.

When used as field-scale mulch, these materials provide effective physical weed suppression comparable to plastic films, with the added advantage of enriching the soil as they decay. The successful validation of diverse materials ranging from rice husks to water hyacinth demonstrates that these solutions can be adapted to regional resources, supporting a circular economy by turning agricultural residues into high-value assets.

In summary, these multipurpose materials are central to the future of sustainable food systems. They empower diverse populations to produce nutrient-dense food, reduce reliance on fossil resources, and close nutrient cycles. Future studies should focus on tailoring fiber compositions to specific crops, standardizing commercial production, and exploring "smart" mats impregnated with biocontrol agents or bioactive compounds to further enhance their agricultural value.

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