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The persistent challenge of alternatives to peat in container-based horticulture: a historical review of the field of growing media

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This paper is a historical review of scientific progress on horticultural growing media, with particular attention to the role of peat and the recurring search for sustainable alternatives. It is well established that peat became the cornerstone of horticultural growing media because it offered a unique combination of nutrient control, pH buffering, water retention, absence of harmful microorganisms, and structural stability. Equally evident are the environmental concerns and sustainability goals that have driven the search for alternative materials since the 1980s. This historical review traces the evolution of growing media from the early 20th century to the mid-2020s, focusing on how peat came to dominate and why its substitution has proven so difficult. Drawing on a wide range of literature, including peer-reviewed experimental studies, historical sources, symposia proceedings, institutional reports, and synthesis articles, the historical development of growing media science and practice across each decade is outlined. Attention is given to various composts, coir, wood fiber, bark, and biochar and challenges with these materials related to product standardization for end-user reliability. While many alternatives show potential, particularly as partial components or as stand-alone media under certain conditions, no single material currently offers a fully viable replacement for peat. Instead, the most promising direction appears to be peat-reduced mixtures optimized for both functionality and sustainability. By understanding how growing media science has evolved and where it has struggled, this paper identifies lessons critical to navigating the ongoing transition toward more sustainable and functional systems.

KEYWORDS

container production, growing media, horticulture, peat, standardization, waste-based

1 Introduction

For almost a century, peat has formed the foundation of the horticultural industry in Europe, valued for its unique combination of high water retention, low weight, structural stability, and absence of weed seeds and pathogens (Michel, 2010; Schmilewski, 2008). These qualities were essential for peat to become the default substrate in modern plant production, underpinning the shift to containerized production as a new system of growing in which media properties, fertilization, irrigation, and climate control were adjusted together (Bunt, 1976).

However, peatlands that depend on continuous water saturation have been degraded for centuries through drainage and use for fuel, agriculture, and forestry (Lindsay, 1993; Robertson, 1993; Sjörs, 1980), and growing awareness of the environmental costs of peat extraction has led to increasing efforts to halt further degradation (Bragg, 1990; Pryce, 1991). The material used in horticulture is primarily the upper, slightly decomposed layers of fibrous *Sphagnum* peat in peat bogs, and its harvesting requires drainage of the bog itself. As a result, horticultural extraction has naturally been included in broader environmental concerns. Biodiversity loss, carbon emissions associated with drainage, and long-term landscape alteration have driven the search for more sustainable alternatives since the 1980s (Alexander et al., 2008; Bragg, 1991; Carlile and Coules, 2011; Verhagen et al., 2009).

Despite decades of research and policy pressure, replacing peat has proven to be a persistent and deeply complex challenge (Gruda et al., 2023; Gruda, 2019; Hirschler and Thrän, 2023). A wide range of organic materials has been tested, including different types of compost, coir, wood fiber, bark, biochar, and various agricultural residues (Bilderback et al., 2013; Jackson et al., 2011). Furthermore, inorganic substrates such as mineral wool, perlite, pumice, and vermiculite have also been widely used in protected horticulture since the 1980s, particularly in hydroponic systems, but they have not served as main components in container-based horticulture due to limited buffering and structural properties. Here, container-based horticulture refers to the cultivation of plants in confined containers such as pots, plug trays, and nursery containers, where the limited substrate volume makes plants especially dependent on the medium for optimal water supply, aeration, nutrient buffering, and anchorage.

While many of the alternatives to peat offer environmental advantages and circular potential, their performance varies strongly with production system. Some alternatives that are considered sustainable, such as wood fiber and compost, can function as stand-alone growing media in fertigated fruiting crops with continuous and precisely controlled water and nutrient supply (Aurdal et al., 2022; Kusnierek et al., 2021; Woznicki et al., 2023). In contrast, in container-based cultivation, where the plant itself is the final product, water and nutrient supply are less continuous and more dependent on the properties of the medium, making reliable peat substitution far more difficult. For this reason, peat has remained the most reliable choice, and substitution has proven especially difficult despite a substantial body of research on alternatives. Meanwhile, the research landscape has become

increasingly fragmented, as efforts to improve functionality, sustainability, and economic feasibility often pull in different directions (Barrett et al., 2016). This paper reviews the historical development of organic growing media as a scientific field expanding from the early 20th century to the present, with particular attention to the rise of peat, the scientific and commercial factors that cemented its dominance, and the ongoing efforts to find viable substitutes. By tracing this development chronologically, the review highlights recurring themes, enduring challenges, and lessons that remain essential for current and future research. Understanding this development is not only a matter of historical interest but also crucial for shaping realistic and functional approaches to sustainable horticulture.

2 The scientific development of growing media

2.1 1900–1930s

The early 20th century saw horticultural growing media develop from trial-based exploratory practice to more systematic experimentation. A defining moment came in 1934, when a crisis emerged at the John Innes Horticultural Institution in England: their primary experimental plant crop, *Primula sinensis*, was devastated by a soil-borne disease in their soil and compost-based potting media. This initiated a rigorous investigation by two horticultural scientists, William Lawrence and John Newell, and resulted in the development of the first standardized recipes for peat-containing, pathogen-free composts, where standardized means fixed component ratios, a defined base fertilizer and lime, and a specified sterilization method. As the recipes were published freely, the horticultural trade quickly adopted them. Within a decade of widespread use across plant species, these media mixtures proved highly successful, becoming essential for predictability and prosperity in plant research and horticulture in general. Remarkably, it only took 4 years to develop the formulae. Lawrence and Newell did hundreds of trials on dozens of different crops starting in 1934 before their formulae were published for everybody in 1938 in their book “Seed and Potting Composts” (Lawrence and Newell, 1939). The standardized recipes became known as the John Innes (J.I.) seed and potting composts, a series of loam-based mixes with prescribed ratios of loam, peat, and sand, plus a defined base fertilizer and lime. By fixing both composition and preparation (including sterilization), the J.I. system enabled reproducible performance across sites and seasons.

Before this breakthrough, growing media, or potting compost as it was called at the time, was based on local materials and diverse recipes. Soil and potting composts were often seen as a mystery and an art, even for the most experienced gardener, difficult to predict and control. Some early scientific literature reports mixtures such as pasture soils combined with manure, sand, or clay (Patterson, 1902) and finely sifted sandy soil mixed with loam and leaf-mold (Macmillan, 1914; Mathews, 1922; Rosenheim, 1917). Specifically, Macmillan (1914) warned against adding manure to potting

compost unless it was thoroughly decomposed. In the 1930s, the recommended mixtures stayed similar: heavy, yet porous, slightly acidic soils (Poesch, 1937), turfy loam, silver sand, and leaf mold (Luxford, 1938). These mixes supported plant growth well, but the incentive to develop more reliable, uniform, disease-free, and high-quality media became increasingly important. Researchers and producers sought consistent results to support scientific progress and improve crop performance. Plant nurseries and research facilities faced challenges at this point in sourcing suitable pasture soils, as they needed significant quantities of high-quality mixes for successful cultivation (Corbett, 1937). Simultaneously, Ogg (1937) explored the potential of *Sphagnum* peats from peatbogs, as this was seen as a vastly available material mainly used as fuel at the time, suggesting composting it with lime, fertilizers, or waste materials to create a usable medium. By the time Ogg and other researchers speculated further on the promise of peat, Lawrence and Newell had already published their book and introduced standardized formulae based on loam as the main component, mixed with peat, sand, superphosphate of lime, ground limestone, and a base fertilizer. These mixtures transformed horticulture by consistently delivering optimal crop results, with very few exceptions (Lawrence, 1949). They explained in their first book that the value of peat in a potting compost was as a conditioning component, because it has a unique spongy nature that aerates and regulates the moisture-holding qualities at the same time, and for a long time, because it decomposes slowly. Peat was also preferred over other organic materials such as leaf mold, because of being highly sterile and free from weed seeds, pests, and diseases, as well as highly uniform in texture and quality.

2.2 1940–1960s

In the decades that followed, efforts concentrated on overcoming the new challenges introduced by containerized, soilless production. Key challenges included loam supply and quality control, the excessive bulk density of loam-based composts that hindered transport and potting, and the need for lighter peat-based substrates with tunable physical and chemical properties. Containerized production of ornamentals and other crops in soilless media had a surge in popularity in the post-war era, and the increasing demand for growing media posed serious problems of supply and quality control of loam (Bunt, 1973). Furthermore, loam-based composts posed challenges for the transportation of plants due to their high density. Growers, therefore, turned to materials other than loam, so-called loam-less or soil-free composts. In response to their need, researchers started developing substrates in the 1950s based more heavily on the peat component that was originally only a fourth of the composition in volume. The peat increasingly replaced loam in volume due to its availability and low density. This trend increased significantly with the emergence of new standardized mixes with peat as the bulk component from the University of California, Davis, in the U.S. in the 1950s (Chandler, 1957). These mixes were called U.C mixes and consisted of varying proportions of peat and sand. The most widely

preferred formulation was peat and sand in a ratio of 3:1 (v/v), and peat rapidly became the most common bulk material for growing media, particularly in countries in the Northern Hemisphere with a large domestic supply. These successful soil-free mixes had relatively low volume weight and performed well in plastic pots that emerged at the time. The J.I mixes soon followed and replaced its loam part of the mixes with peat (Woods et al., 1967). A major international movement away from loam-and-compost-based mixes for most horticulture crops followed into the 1960s, and research was done to optimize the physical and chemical properties of different types of peat (An Foras Talúntais, 1969; Klougart and Bagge Olsen, 1968).

2.3 1970s–1980s

As the 1970s emerged, container production systems, also called soilless systems, kept modernizing and gained numerous benefits of further optimized nutrition, water, and oxygen levels while avoiding soilborne diseases and salinity in a controlled system. Research demonstrated superior yields of soilless media over traditional field cultivation (Pérez Melián, 1976), and efforts to refine this type of cultivation for new crops accelerated. Further development of soilless growing media and tailored mixes continued as access to loam as a component decreased (Bunt, 1976). With the adoption of peat-based mixes globally, the demand for consistent mix quality for specific applications has increased. Uniformity in the structure and properties of growing media was essential to produce reliable plant products. The grading standards for peat, however, were not yet sufficiently rigorous, leading to the recognition of a need to understand and enhance the properties of the peat/sand mixes. A new great attention to exact physical properties such as bulk density, pore-space, air capacity, water capacity, and water retention arose. Several researchers declared new terms for physical qualities specifically for growing media in containers and simultaneously demonstrated clear physical advantages in white *Sphagnum* peat compared to other common organic components of growing media (De Boodt and Verdonck, 1971; De Boodt et al., 1972, 1973; Goh and Haynes, 1977). More problems in nursery production were being solved by exact mixing of materials and understanding the physical properties, such as using a small proportion of pine bark in addition to sand as physical amendments to create better drainage and avoid losses to waterlogging and freezing. Concurrently, the development of a method for measuring air-filled porosity in mixes enhanced the ability to adjust mix proportions for specific production systems (Bragg and Chambers, 1987). The interest in improving combinations of mainly *Sphagnum* peat and fine sand continued to grow, driven by their favorable physical properties and by their ready availability in the vast peatlands of the Northern Hemisphere, where grading to a standard was now possible (Boggie, 1970; Bunt, 1973). A landmark account of peat classification and use for plant production was provided by Puustjarvi (1977), who described differences in occurrence, decomposition stage, and horticultural properties of various peat types. These classifications underpinned

the growing media industry's recognition that peat was not a single uniform resource but a spectrum of materials with distinct functional characteristics.

Documentation of the benefits of using peat as a growing medium for the wider sector in terms of performance, economic considerations, and favorable properties continued throughout the 1980s (Abad et al., 1988; Radjagukguk and Soeseno, 1983; Tahvonen, 1982). Bark was a common component, but posed challenges due to the long time required for composting and maturation to break down phytotoxic phenols and tannins. Solbraa (1979) reported issues with certain conifer species in northern Europe exhibiting high and toxic concentrations of manganese in the bulk of waterlogged bark substrate.

Some alternatives to peat were being reviewed at the time by Cull (1981), who concluded that out of the various bulky organic materials tested as a container media instead of peat, "Not one stands out as the alternative to peat in the UK". A later review by Wilson (1985) looked at a wider range of materials, including inert mineral substrates such as mineral wool, vermiculite, and perlite, and these materials did have a large place in modernizing horticulture, particularly mineral wool as an optimized stand-alone substrate. It performed well in cutting propagation systems for several ornamental crops (Gislerød, 1987; Lee and Goldsberry, 1988), and it is highly effective in intensive greenhouse cultivation of fruit crops such as tomato and cucumber (Boertje, 1985; Noordam, 1987; Wilson, 1985). Mineral wool and other inert substrates had also been introduced to solve specific physiological challenges in hydroponic systems. For instance, in nutrient film technique (NFT) setups, peat-based composts often led to poor root aeration, while inorganic media such as mineral wool and perlite significantly improved oxygen availability and eliminated symptoms of waterlogging (Jackson et al., 1984). More broadly, mineral wool, together with peat, became emblematic of a broader shift toward total control over plant growth, enabled by fully artificial or uniform substrates and computerized climate and fertigation systems (Welleman and Verwer, 1983). Mineral wool is an inert substrate manufactured to tight, reproducible specifications and performs well under tightly controlled conditions. However, it lacks the broader versatility, buffering capacity, and organic structure required for general container nursery production and, thus, did not emerge as a competing substitute for peat in the wider horticultural sector. This underlines the contrasts in different cultivation systems. Inert or low-buffer substrates perform reliably in tightly controlled, continuously fertigated fruiting crops, whereas nursery and potted plant production without continuous root-zone supply remains far more sensitive to the intrinsic physical and chemical properties of the medium.

Peat rapidly became very cost-effective (Prasad, 1979) and remained the most popular bulk material for growing media worldwide. Studies in the 1960s and 1970s showed that growers initially struggled to adapt their watering regimes to the new peat-dominant mixes, which had much higher water retention than loam-based substrates (Kaukovirta, 1967; Sonneveld and Voogt, 1975). Over time, however, growers adjusted their practices, and by

the late 1980s, all-peat mixes had become the market standard because of their reliability, performance, and low weight (Schmielewski, 2008).

However, this was the last decade in which peat was regarded as an exclusively remarkable material in horticulture. By the 1980s, a more complex ecological understanding was emerging. Sjörs (1980) described peatlands as carbon-storing ecosystems with unique biodiversity, while Ryan and Cross (1984) documented rapid degradation in Ireland due to turf cutting for fuel and afforestation. Although horticultural use was not yet singled out, studies like these marked a shift toward recognizing peatlands as vulnerable ecosystems and a scrutiny of all forms of extraction.

2.4 1990s

The real push away from peat was propelled in the 1990s by the increasingly strong concern not only for conservation and wildlife but also for carbon emissions. Prior to this time, resources meant as growing medium in horticulture were judged solely by their chemical, physical, biological, and economic characteristics. Now, however, a social climate arose that looked increasingly at the wider environmental impact of its extraction, production, and use. This shift first took hold in Britain and then spread across Europe, strengthened by the 1992 EU Habitats Directive, which designated raised and blanket bogs as priority habitats and prioritized their protection. Lindsay (1993) described peatlands as rare habitats at the boundary between water and land and documented that in lowland England, some 37,000 ha had been reduced to fewer than 500 ha of natural bog, with comparable losses across Europe. The use of peat came to be regarded as an unsustainable practice in Europe, and major campaigns against its use were mounted in several countries, especially the United Kingdom (Carlile, 1997). At this point, however, the price of peat had become remarkably low due to advances in extraction and processing technologies, economies of scale in production, and the globalization of the peat market. Peat was now considered both an integral and affordable growing medium, and simply ceasing its use immediately, particularly as a potting medium, was not feasible or practical (Bragg, 1990, 1991, 1998; Robertson, 1993).

Books and reports examining the environmental impacts of peat extraction and potential alternatives contributed to shaping the discussion and guiding the development of new growing media (Benington and Steel, 1994; Lindsay, 1993; Pryce, 1991). Pryce (1991) discussed the main issues involved in the topic of peat conservation and peat alternatives. Peat was acknowledged as an undeniably remarkable material for plant cultivation with several characteristics that make it a good medium for all purposes in horticulture, and that no single peat alternative up to that point could perform all the roles that peat currently plays in the horticulture sector. It was easy to reduce peat use to some extent by replacing it as a soil amendment with composts, but finding alternatives for all aspects of horticulture was declared by Pryce to be a challenging task that called for sector-specific solutions, more research, and a cultural shift toward sustainable practices.

Carlile (2001) documented the intensifying environmental and political pressures on peat use in UK horticulture between 1997 and 2001. Despite growing public awareness and strong lobbying by organizations such as the Royal Society for the Protection of Birds and Plantlife, actual peat use increased significantly during the 1990s, from ~1 million m³ in 1990 to 3.4 million m³ by 1999. Notably, 62% of this volume was used by amateur gardeners, making retail the primary target for campaign efforts. The UK government responded with planning reforms, market monitoring, and the formation of the Peat Working Group, which recommended shifting extraction away from conservation areas and promoting peat-free alternatives. Targets were introduced to ensure that 40% of the growing media and soil improver market would be peat-free by 2005. However, alternative materials remained marginal in commercial use, and the public showed little willingness to change habits (Carlile, 2001). The Peat Producers Association acknowledged the environmental debate but defended the economic and horticultural viability of peat, promoting partial dilution (20%–25%) rather than full substitution.

The most challenging aspect was replacing peat as the main component of growing media in container production, where achieving an optimal balance of air- and water-filled pores for the roots is crucial. While co-composted materials gained more traction in landscaping and low-value applications, their adoption in high-value horticulture, such as pot plant production, lagged (Pryce, 1991; Szmidt, 1998). There had been 40 years of optimizing peat; surely, alternative materials would need a similar timeframe to emerge as excellent replacers.

At this point, replacing peat had already shown itself to be a formidable challenge. As pointed out by Riviere and Caron (1999), the environmental concern was not only about limiting peat use but also about finding scientifically and technically sound substitutes from industrial by-products. The challenge was not simply replacement but ensuring environmental and social compatibility at scale. Research grew more complex, now shifting from focusing merely on stored reserves of water and air, to understanding how these elements move within the substrate–plant–atmosphere continuum. The ability of new media to deliver consistent fluxes of water, nutrients, and gases was seen as vital for replacing peat's unique functional profile. Furthermore, the biostability of organic alternatives was a concern. Unlike peat, many alternatives decompose during cultivation, altering their structure and performance. This underlined the need for new predictive indices and standardization efforts to ensure the reliability of peat-free media.

2.5 2000s

Challenges in standardization and quality control became increasingly apparent in the 2000s. Analytical methods varied across Europe, complicating data interpretation and making product comparison difficult. Efforts by the European Standardization (CEN) to harmonize methodologies encountered resistance due to inconsistent national regulations and

implementation hurdles (Baumgarten, 2005). In parallel, improving compost quality became a major focus, particularly through co-composting and the targeted use of additives to reduce variability and enhance reliability (Barth et al., 2008). However, variability in input materials and the lack of ongoing optimization and site-specific adjustments remain major barriers to achieve high-quality compost suitable for growing media.

According to Schmilewski (2007), the early 2000s saw a growing use of alternative materials to reduce peat content in horticultural substrates across the EU. The most commonly adopted alternatives included composted bark, green compost, wood fiber, and coconut coir. These materials were selected for their physical and chemical properties, such as improved aeration, drainage, and water retention, as well as for their alignment with emerging sustainability goals and waste valorization strategies. However, their adoption varied considerably by region, depending on factors such as local availability, waste policy, and production systems.

Bohlin and Holmberg (2001) reviewed the state of growing media use in Swedish horticulture, emphasizing that Swedish growers almost exclusively relied on ready-mixed, peat-based substrates, especially in pot and bedding plants, nursery stock, forest seedlings, and bulb forcing. Green compost, bark, and coir had been trialed but were not adopted commercially due to quality issues or lack of clear benefits. The authors argued that horticultural peat use in Sweden was sustainable at current levels, citing domestic oversupply and a relatively small fraction of peatland in active production. In contrast, Wever et al. (2002) reported on Dutch efforts to transition toward more durable growing media under rising environmental and regulatory pressure. At the time, Dutch horticulture relied on 3.4 million m³ of peat used annually and only a minor uptake of alternatives like coir, bark, and compost. The Dutch Ministry of Agriculture initiated a multiyear research project aimed at improving sustainability through either the development of alternative materials (e.g., coir, UF foam, wood fiber, hemp, *Miscanthus*) or the more efficient use of existing ones via reuse or extended life cycle. Compost from vegetable, fruit, and garden waste (VFG) showed limited potential, substituting for up to 30% of peat when chemically treated, though concerns remained around pH, EC, and heavy metals.

Verhagen and Blok (2007) provided a further detailed account of trends in the Dutch horticultural sector between 2001 and 2005. While peat remained the dominant component, the share of organic alternatives rose by about five to six percentage points between 2001 and 2005, with compost alone adding roughly one and a half points. However, this increase occurred primarily in retail products marketed as soil improvers, not in professional growing media. The authors emphasized that technical performance and crop reliability continued to make peat the preferred material in high-value professional production, where substitution remained limited.

Rivière et al. (2005) provided an overview of growing media use in French horticulture during the early 2000s, based on industry data and sectoral analysis. The French market was still highly reliant on peat, with 70% of the total growing media volume. Alternatives such as composted bark, green compost, wood fiber, and coir were in use but remained secondary components, primarily in blends.

The report also highlighted that peat reduction was more advanced in the amateur retail market, driven by consumer preferences and policy signals, whereas the professional sector continued to prioritize consistency and crop performance.

Replacing peat proved more complex than anticipated. By 2008, critical voices began to specifically articulate the depth of the challenges involved. From a technical standpoint, [Schmilewski \(2008\)](#) argued that peat remained essential in growing media due to its unmatched reliability and physical properties. Although environmental pressure and waste policies had driven extensive research into alternatives, most materials tested were only marginally suitable. He concluded that continued dependence on peat was likely, at least in blended formulations. From a conservation perspective, [Alexander et al. \(2008\)](#) reviewed the UK's policy and conservation response to the environmental impacts of peat use in horticulture and emphasized the persistent disconnect between environmental policy goals and the realities of horticultural practice in the UK. Despite the rise of voluntary initiatives such as the Growing Media Initiative (GMI) and government targets, peat reduction had made limited inroads into the professional sector, where performance demands remained high. The authors argued that without stronger regulation and institutional leadership, market forces alone would not deliver meaningful change.

[Waller \(2012\)](#) provides an overview of peat substitution in the UK as of 2009, detailing the volumetric distribution of alternative materials used in peat-free blends. At this point, bark accounted for 32% of all peat substitutes by volume, followed by green compost (26%), wood fiber (16%), loam (14%), and coir and other materials (12%). These changes were largely driven by national policy targets and voluntary industry initiatives, particularly in the retail market, where most progress in peat reduction had occurred.

2.6 2010s

During the 2010s, the search for alternatives to peat gained significant momentum, with a wide range of substitute materials being actively studied and promoted. The focus on sustainability was further advanced by the establishment of the Sustainable Growing Media Task Force in 2011, which sought to expand the focus from merely reducing peat use to ensuring the overall sustainability of all horticultural growing media ([Dawson, 2012](#)). At the beginning of this decade, only 20% of growing media volume used within the EU consisted of materials other than peat at that time, indicating a persisting peat dependence and the challenges involved in transitioning to more sustainable alternatives ([Gruda, 2011](#)). Reports published in 2015 documented a continued push toward sustainable substrates, particularly through increased use of organic materials other than peat ([Schmilewski, 2015](#); [Van Os, 2015](#)). The revision of the EU Ecolabel Criteria further reinforced this by promoting the use of renewable inputs and aiming to reduce environmental impact ([Quintero et al., 2015](#)).

Notably, a long-established trend had now become the norm: in order to reduce costs and improve efficiency, growers relied on

commercially available, ready-to-use growing media rather than producing their own ([Barrett et al., 2016](#)). This meant that growing media manufacturers were the ones tasked with producing substrates that were both peat-free and sustainable, while still delivering the reliability and functional performance that growers depend on.

One of the main responses in Europe during this decade to rapidly decrease the use of peat was to significantly increase the import of coir as a peat-free component in growing media. Importantly, coir has proven technically successful as a peat-free medium in several high-value crops. In Europe, coir slabs and growbags are widely used in commercial greenhouse production of tomato, cucumber, and strawberry ([Carlile et al., 2015](#); [Olle et al., 2012](#)). These studies demonstrate that coir is one of the few alternatives to peat that has reached commercial scale. However, concerns remain regarding its sustainability due to long-distance transport and processing requirements. By 2012–2013, coir pith alone accounted for nearly half (48.5%) of India's total coir exports by volume, with the EU receiving over a quarter of all Indian coir exports (26% by quantity and 33% by value) ([Coir Board of India, 2014](#)). Countries such as the Netherlands, Germany, the UK, and France were among the top European importers, reflecting the region's growing reliance on coir as an alternative to peat in professional horticulture. While coir performs well in life cycle assessments due to its renewable status and low emissions per volume, [Carlile and Coules \(2011\)](#) note that its long-distance transport from Asia and the need for careful processing to reduce salinity raise environmental and logistical concerns. From a sustainability standpoint, the use of locally sourced organic waste materials would be a more desirable solution.

Like in previous decades, there is a great emphasis on compost as a component in research on alternatives because it facilitates waste reuse. [Raviv \(2011\)](#) underscored this perspective by conducting a SWOT analysis on composts as growing media components, which resulted in a promise of low cost, disease suppressiveness, and nutritional contributions, but also highlighted challenges with issues of uniformity, salinity, and the necessity for rigorous quality control to mitigate the risk of pathogens and heavy metals. More extensive research, such as by [Moral et al. \(2011\)](#), focused on demonstrating that optimized composting processes and advanced strategies could contribute significantly to the growing media market by providing large quantities of organic material that meet high-quality standards. Similarly, [Carlile et al. \(2015\)](#) wrote about constituents and properties of organic growing media and emphasized that much research has been focused worldwide on the transformation of agricultural, industrial, and municipal waste resources that can be used in growing media, with the benefit of diverting wastes from landfills and land spreading. According to such research, large quantities of waste-based organic growing media would be available in the future. Other biomasses emphasized by research at this time were whole pine trees derived from plantation thinning and waste or "slash" from forest residues in the United States ([Bilderback et al., 2013](#); [Fields et al., 2014](#)), solid digestate from biogas plants ([Crippa et al., 2011](#); [Do and Scherer, 2012](#)), and the use of biochar ([Altland and Locke, 2013](#); [Zaccheo et al., 2013](#)).

However, it is noteworthy that this decade produced a continuous stream of research, reports, and articles that highlighted the potential of waste-derived materials as substitutes, yet with practical integration remaining limited. Now was the time for more critical reflection on the actual progress made in developing alternative, waste-based peat-free growing media, as the limitations and trade-offs were becoming increasingly difficult to ignore. Jackson et al. (2011) pointed out that while there was no shortage of potential substitutes in the form of municipal, agricultural, and industrial by-products, the real-world integration of these alternatives faced significant hurdles such as regional availability, consistency, and additional costs for transport and handling. Blievernicht et al. (2012) emphasized that while many materials were tested recently to replace peat, still none could fully replicate its functionality. The promising materials like wood fiber, bark, and green compost had limitations, often only capable of replacing a maximum of 30% of peat in growing media mixes. Neumaier and Meinken (2012) reflected on efforts since the early 1980s to reduce peat use, highlighting how the range of viable materials remained constrained by physical, chemical, and economic factors, as well as competition from sectors such as renewable energy. Barrett et al. (2016) thoroughly analyzed why certain materials have gained widespread adoption while others, despite considerable research attention, have not. Their review highlights how much of the existing literature emphasizes the chemical, physical, biological, and more recently, environmental properties of growing media components, while often overlooking the practical and economic factors that ultimately shape their use and availability. Three main reasons were identified for why such few organic materials were commonly used at the time, despite the ongoing criticism of peat extraction and emphasis on new materials. Firstly, the alternative materials studied have been selected predominantly with environmental drivers in mind, with significantly less consideration given to performance and economic cost. Secondly, the characterization of these materials is carried out using a wide variety of approaches, producing results that are difficult to compare and interpret among different materials. Finally, few researchers consider the commercial realities of growing media manufacture, such as whether the volume of material available is sufficient to meet demand or whether there are any legislative constraints that might impede uptake. As quoted from Barrett's review, "the physical, chemical, and to a lesser extent biological characteristics of growing media materials have been investigated quite extensively over the last 40 years; whereas practical considerations have received relatively little research focus."

Furthermore, Watson et al. (2019) offered a particularly vivid critique through an analogy with rocket design: just as it would be absurd to build rockets without knowing the required escape velocity or how thrust and fuel capacity contribute to achieving it, they argued it is equally problematic to develop growing media mixtures through trial and error without clear, quantifiable targets. They proposed a parameter-based framework in which materials are visualized within a three-dimensional parameter space and described using the three key physical values of growing media:

air-filled porosity, dry bulk density, and available water. This approach should enable researchers to define target characteristics and then design, evaluate, and refine growing media mixtures systematically, based on their location within that space. With this approach, the goal is to reduce the number of trials and improve their relevance by anchoring formulation strategies in measurable properties and predictable trajectories.

The status of sustainable growing media for this decade can be considered as summarized in a review by Gruda (2019), which surveyed a wide array of peat alternatives and concluded mainly, like others before, that persistent barriers to a broader adoption, such as variability in quality, limited availability, high transport emissions, and poor integration into commercial production systems, persisted. The review also reiterated, just in case there was any lingering uncertainty, that future growing media must be agronomically effective, locally available, economically feasible, and environmentally sustainable.

Given these persistent constraints, researchers increasingly recognized that no single material could match the multifunctionality of peat, with the exception of coir. Blends allow the complementary strengths of individual substrates to be combined while offsetting their weaknesses, making them a critical route toward peat replacement. Carlile et al. (2015) show that commercial substrates are already formulated as mixtures. For example, peat is routinely combined with coir, wood fiber, or compost to balance air space, water holding, and nutrient supply without relying on any single material. Ceglie et al. (2015) use mixture-design experiments with green compost, palm-fiber waste, and peat to demonstrate that blends can outperform single materials. Mulholland et al. (2017) experiment with a predictive blending methodology by targeting the physical properties of peat and formulating a coir/bark/wood fiber/compost mixes that match peat controls in trials. Together, these studies illustrate a shift from empirical substitution toward systematic formulation strategies, with blending emerging as the most practical pathway for reducing peat reliance in commercial growing media.

2.7 2020s

The 2020s have seen intensified efforts to replace peat, framed by stronger climate targets and circular economy goals. The establishment of the Growing Media Initiative (GMI) reflects efforts to promote peat-free alternatives, with organic horticulture at the forefront of this transition (Lennartsson and Conroy, 2021). This time is marked by a growing emphasis on resource-saving production systems based on the principles of reduce, reuse, and recycle (Atzori et al., 2021; Gruda, 2019; Macmillan, 1914; Streminska et al., 2021).

Pressure on finding alternatives to peat increases, but so does the persistent complexity. Reviews and reports from this decade highlight similar patterns as before about the array of studied alternatives (Blok et al., 2024; Hirschler and Thrän, 2023; Kader et al., 2024; Mariotti et al., 2023). They confirm that alternative materials show promise under specific conditions, but challenges of regional supply, quality consistency, contamination risk, functional

reliability, and economic feasibility still limit large-scale adoption. Each proposed innovation, rather than resolving the issue, often exposes new layers of complexity, leaving the search for a viable, universal peat alternative as unfinished as ever.

In light of the functional shortcomings of many peat-free materials, microbiological activity is often seen as a possible compensatory factor. Because alternative substrates such as various types of compost, wood fiber, and biochar tend to support more diverse and active microbial communities than peat (Pot et al., 2021, 2022), researchers have long hoped that these microbiomes might enhance disease suppression, nutrient cycling, and overall plant health. Targeted experiments have demonstrated some success, for instance, with compost–*Trichoderma* blends for disease suppression (Fuchs et al., 2016) or microbiome shaping for nutrient cycling (Debode et al., 2018), but these outcomes remain difficult to replicate consistently. Despite advances in microbial profiling and sequencing technologies, efforts to steer microbial functions in a safe and reproducible manner remain largely undeveloped (Järvenpää et al., 2021). Recent reviews highlight high variability in feedstocks and a lack of standardized evaluation protocols, which limits comparability and commercial reliability for peat alternatives (Gruda, 2019; Kader et al., 2024; Mariotti et al., 2023). As Blok et al. (2024) suggest, microbiology may play a more deliberate role in future disease management strategies, but for now, it remains an unpredictable factor. Moreover, certain peat-free substrates have been shown to support the persistence of plant and human pathogens under greenhouse conditions, underscoring the need for more rigorous control over feedstocks and sanitization (Litterick et al., 2025).

Practical challenges with peat-free media are demonstrated by a range of qualitative studies. Surveys in Northern Europe show both interest and frustration among gardeners and professionals, with users reporting poor growth and germination in peat-free media composed of alternatives such as composted bark, green compost, wood fiber, and coir, underscoring the need for further development (Hirschler and Thrän, 2023; McKinnon and Bätnes, 2022). Koseoglu et al. (2023) provide an extensive analysis of the challenges and opportunities for peat substitution, highlighting that the elimination of peat from growing media is constrained by limited availability and inconsistent quality of alternatives, elevated costs, contamination and storage issues, the market dominance of price-sensitive retailers, and low consumer familiarity with peat-free products. Braun et al. (2024) show that peat-free substrates are largely absent from gardeners' social discourse, with purchasing decisions driven more by habit and price than sustainability, and this suggests that communication strategies should prioritize functionality over abstract sustainability messaging. Functionality remains the primary driver of growing media choices, while sustainability only gains traction when it aligns with performance.

Although the transition remains challenging, the key materials for peat substitution in horticulture can now be defined as coir, wood fiber, composted green waste, and bark, while biochar, sustainably cultivated *Sphagnum* (including acrotelm) moss, and straw-like fibers are promising but still require further stabilization,

sanitization, and supply development before wider use (Blok et al., 2024). The benefits and drawbacks of the materials are well known by now and can be easily summarized: Coir is valued as a waste by-product but is criticized in the Northern Hemisphere for its transportation emissions and inconsistent quality (Hirschler and Thrän, 2023; Paoli et al., 2022). Wood fibers and other plant-based constituents, such as *Miscanthus*, offer excellent aeration and structure as growing media components. These materials are available in large quantities and, in the case of wood fibers, can be manufactured with a more homogeneous fiber structure, yielding consistent aeration. However, they are prone to nitrogen immobilization and rapid microbial degradation, leading to structural collapse unless fertilization and potting practices are carefully managed (Gruda et al., 2023). Wood fibers hold considerable potential for specific horticultural applications and are increasingly being explored both as a stand-alone substrate in hydroponic systems and as a component in growing media up to 50% in volume, particularly in regions with abundant forestry resources (Eveleens et al., 2021; Haraldsen et al., 2023; Kusnierek et al., 2021; Vandecasteele et al., 2023; Woznicki et al., 2023, 2021). Composted green waste is environmentally attractive, though it presents challenges related to nutrient variability and weight, and compost of sufficient quality for use in growing media for container production remains scarce due to limitations in feedstock selection, processing, and infrastructure (Hirschler and Thrän, 2023). Bark, particularly when composted or aged, has good air capacity and moderate structural stability over time, but offers low water-holding capacity, variable quality, and risks of nitrogen immobilization or phytotoxicity unless properly processed. Its availability is constrained by competing uses such as bioenergy and mulch, and it is best used as a partial component in growing media (Blok et al., 2024; Gruda et al., 2023). Biochar may enhance plant growth at certain doses, but it is costly to produce. There is extensive research on biochar, showing highly variable results depending on factors such as feedstock composition, processing methods, and application rates. Most studies indicate that inclusion levels of only up to 10%–15% can be beneficial (Graber, 2021; Joseph et al., 2021). Other waste materials, such as residual waste from biogas plants, are considered in urban horticulture due to their promising circular aspect (Atzori et al., 2021); however, they are not suitable as a primary component due to low structural stability, high salt content, low water buffering capacity, and concerns with odor and contamination (Blok et al., 2024; Gruda et al., 2023).

At present, no material offers a universal solution, making careful formulation and management essential. Seedlings and transplants remain particularly reliant on peat-based media for optimal performance. Studies show that mixes with at least 50% peat consistently outperform alternatives in terms of growth and nutrient uptake (Carey et al., 2024; Čepulienė et al., 2024). As an example of recent research trials, total or high peat substitution with materials such as various types of biochar and compost has sometimes resulted in plant failure due to unsuitable pH or electrical conductivity (Nocentini et al., 2024). Even in hydroponic systems, which can be considered to have less requirement for optimal growing media compared to traditional

container-based horticulture, peat-based media continue to provide superior results for seedling development (Ferrarezi et al., 2024).

A growing response to this is a notable interest in using forms of fresh and sustainably produced peat moss, either as *Sphagnum* moss cultivated hydroponically or as acrotelm material produced through paludiculture, as a potential future solution (Blok et al., 2024; Friis Pedersen and Løes, 2022; Müller and Glatzel, 2021). Furthermore, Blok et al. (2024) advocate a gradual substitution strategy, aiming for 50% renewable content by 2030, alongside investments in processing and quality assurance. They also suggest that a limited, strategic use of peat may remain necessary to safeguard horticultural functionality during the transition. In parallel, emerging experiments under protected cultivation indicate that direct reuse of growing media across several cultivation cycles can maintain production performance when reuse is managed and end-of-cycle fertigation is adjusted to lower residual nutrient loads, offering a practical route to reduce virgin peat demand (Vandecasteele et al., 2024; Woznicki et al., 2024).

Recent projections reinforce the historical pattern that has characterized growing media development. Global demand, estimated at 116 Mm³ in 2022, is expected to more than double by 2050 and reach 280–325 Mm³ (Nguyen et al., 2025). Although renewable constituents such as wood fiber, compost, bark, and coir are projected to expand sharply, peat will still account for approximately 21% of total use, down from more than half in 2022. Even under optimistic scenarios, an additional 22–32 Mm³ must be supplied through new materials or reuse strategies. These projections illustrate that peat continues to occupy a central role despite sustained efforts to replace it, echoing the historical record of repeated but incomplete substitution. The persistence of peat in future scenarios underscores the enduring challenge of finding sustainable alternatives that combine functionality, availability, and economic feasibility.

3 Summary and recommendations

Scientific progress in horticulture has long relied on distilling the intuitive expertise of skilled growers and researchers into repeatable knowledge and precision. As Sir Daniel Hall wrote in the foreword to Lawrence and Newell (1939), “The first task of the scientific man who is working on behalf of any of the arts or crafts is to try to standardize the process which the best practitioners carry out with such eminent success.” He continued, “The aim of science is to replace this hard-won experience by something more definite and more certain, for it is a maxim of science that a thing is not true until it can be repeated at will.” By “hard-won experience,” he was referring to the intuitive knowledge a gardener or researcher gains through years of trial and observation.

As the historical development presented in this paper has shown, contemporary peat-free growing media seem to contrast with this. The evolution of growing media has shifted from a sole focus on precision and functionality to a prolonged and frustrating pursuit of growing media mixtures that are meant to combine functional and precise performance with complicated sustainable materials. Vast amounts of documented hard-won experience with potential new alternative growing media have been accumulated by researchers

in the field of growing media the last decades, the number of scientific peer reviewed trials is in the hundreds for various waste-based or other promising materials, but something definite and certain cannot possibly appear from uncoordinated and often exploratory trials with materials that are still a major challenge to standardize.

The development has seemingly traced a circle, from the fragmented trial-and-error practices of the early 19th century with various composts and local materials, through the clarity achieved with Lawrence and Newell’s standardized compositions in the 1940s, and now back to a patchwork of varied and unsettled approaches. Even though today’s work is grounded in scientific methodology and a vast understanding of the parameters, researchers face a proliferation of materials, inconsistent performance, and the absence of reliable standards for almost all sustainable peat alternatives. Unique for this time is the complexity of the context, the search for functional growing media takes place within a highly diverse and globalized horticultural sector under pressure to meet environmental and political demands, while a broader society carries the parallel responsibility of converting waste into consistent, usable raw materials.

Encouragingly, the large body of research shows that peat-free blends are readily used in production where fertigation supplies water and nutrients directly to the roots continuously, and fruits or vegetables are harvested as the crop. The challenge is greater in containerized systems such as plugs, potted plants, and nursery crops, where the plant itself is the product and entirely dependent on the medium. For these systems, great progress and potential can be found so far in *peat-reduced* solutions. By retaining 25%–50% peat alongside renewable components such as wood fiber, coir, bark, or compost, it seems possible to combine environmental gains with the functional reliability required by professional horticulture.

In these mixtures, peat functions as a conditioning agent, providing stability by balancing pH, water retention, and structural integrity. This echoes the early development of specified compositions in the 1930s and 1940s, when peat was a 25% component alongside loam from composted turf and sand. By shifting the focus from replacing peat entirely in container-based horticulture to changing the bulk material while retaining a significant amount of peat as a conditioning agent, and where feasible, reusing substrates across multiple crop cycles, the prospects for developing sustainable growing media become considerably more promising.

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