nutrient solution composition and reduces nutrient leaching (Tang et al., 2024). However, strong microbial immobilization or adsorption may temporarily reduce the availability of N, P, and S. In peat-sawdust substrates, it has been observed that initial fertilization is needed to alleviate nutrient immobilization (Depardieu et al., 2016).

2.3 Biological properties

From a biological perspective, the substrate is not only a habitat for microbial communities but also an important factor in regulating nutrient cycling, promoting plant growth, and suppressing diseases. Substrates amended with organic materials (such as livestock manure, vermicompost, mushroom residues, or organic fertilizers) usually contain higher populations of bacteria and fungi, are enriched with phosphate-solubilizing and nitrogen-fixing bacteria (e.g., Azotobacter), and show higher enzyme activities related to carbon and nitrogen cycling (Hindersah et al., 2023).

Amendments such as vermicompost and livestock manure can improve substrate fertility, increase microbial abundance and enzyme activity, and reduce the accumulation of phenolic acids. As a result, they significantly promote plant height, leaf area, root length, and fruit yield and quality, especially in continuous cropping systems (Bai et al., 2025). Sheep manure organic fertilizer can significantly improve soil pH, nutrient availability, and the activity of enzymes such as sucrase, protease, and urease, while also increasing bacterial and fungal diversity, thereby promoting strawberry growth and nutrient supply (Zha et al., 2024).

An ideal substrate should also have some disease-suppressive ability. This mainly comes from good aeration and drainage conditions (which are unfavorable for many root pathogens) and microbial communities that can compete with or antagonize pathogens. Compared with greenhouse soil, artificial substrates can change the composition and functional pathways of rhizosphere bacterial communities in strawberry, showing enrichment in plant growth-related metabolic pathways (such as flavonoid biosynthesis) and changes in antimicrobial compound synthesis pathways (Zhang et al., 2023).

Substrates with good physical and chemical conditions (such as coir-perlite-vermicompost mixtures, peat combined with rice husk or perlite, and optimized vermicompost-coir/biochar formulations) can promote dense root branching and high survival rates. This increases the surface area for beneficial microbial colonization, further improving nutrient uptake efficiency, yield, and system stability (Yafuso and Boldt, 2024; Selivanova et al., 2025).

3 Common Substrate Types and Their Performance

3.1 Organic substrates

Among organic substrates, coir, peat, compost, and vermicompost-based media are the most widely used. Pure coir or coir-based mixtures have high water-holding capacity, good aeration, and low bulk density, which support strong vegetative growth and canopy development. In both open-field and greenhouse trials, 100% coir or peat-perlite mixtures produced yields comparable to soil cultivation, while also forming larger canopies and higher biomass (Wang et al., 2016).

Peat remains an important reference substrate due to its favorable structural properties and high cation exchange capacity (CEC). Commercial peat-based mixtures (such as peat combined with coir, perlite, vermiculite, or zeolite) often support strong root growth and high long-term productivity in both pot and hydroponic systems (Lee et al., 2023) (Figure 1). Compost- and vermicompost-based substrates can increase organic matter content, improve nutrient supply, and stimulate microbial activity. In particular, mixtures of vermicompost-coir and vermicompost-biochar at about a 0.5:0.1 ratio significantly improved water retention, nitrogen use efficiency, enzyme activity, nutrient uptake, as well as fruit yield and quality (Tang et al., 2024).

However, organic substrates may also have some drawbacks, such as compaction, high electrical conductivity (EC), and nutrient immobilization. For example, peat mixed with sawdust or bark often requires additional fertilization at the early stage to overcome the immobilization of nitrogen, phosphorus, and sulfur. Pure coir may also become compacted under certain conditions, and compared with treatments containing mineral amendments, it may result in fewer fruits (García-López and Cruz-Ortega, 2023).