

and flexible soilless cultivation systems. However, these technical means still face certain bottlenecks in the application process, such as high energy consumption, excessive environmental metabolic load, and high requirements for temperature control stability (Lu et al., 2023; Mousavi et al., 2023; De Oliveira Bernardo et al., 2024; Kouloumprouka Zacharaki et al., 2024).

In the 1980s, strawberries were introduced from Japan to Zhejiang for cultivation and gradually became one of the most representative high-efficiency specialty industries in the province. Currently, Zhejiang has emerged as a major production base for facility-grown strawberries nationwide, with an annual planting area of 6,000 hectares, an output of 120,000 tons, and a value exceeding 2.8 billion yuan. Two key production areas have initially formed: Hangzhou and Ningbo, with Jinhua City standing out as the largest in the province and among the top in China, earning the title of "China's Strawberry Hometown". From December to February of each year, strawberries enter a concentrated market period, leading to significant price drops and partial sales stagnation in some regions, resulting in unstable planting benefits. To address this, Zhejiang has adopted measures such as planting early, mid, and late-season varieties to extend the strawberry supply period and balance market availability; employing practical techniques like trellis-based three-dimensional cultivation, soilless cultivation at the grassroots level, and integrated water and fertilizer management; and selecting a mix of red, pink, and white strawberry varieties to diversify fruit types and enhance appeal (Figure 1). These efforts aim to achieve year-round strawberry cultivation and improve planting economic efficiency.



Figure 1 Strawberry Base of Jinhua Yudi Family Farm Co., Ltd. (Photoed by Guojia Ni)

This study aims to systematically sort out and evaluate the environmental control technology paths required to achieve high-quality year-round supply of strawberries, and conduct in-depth discussions on the actual performance of greenhouse structural engineering design, soilless substrate performance optimization, automation equipment integration, and sensor monitoring digital technology. At the same time, we will also focus on the ability of these technologies to achieve a balance between yield, quality and sustainable development goals, strive to provide a theoretical basis for the iteration of related technologies, and provide a feasible reference for the strawberry industry to achieve efficient, environmentally friendly and sustainable development.

2 Physiological Basis and Environmental Requirements for Year-round Cultivation of Strawberries

2.1 Characteristics of vegetative and reproductive growth of strawberries

The root system of strawberry plants is shallowly distributed, and the typical fibrous root system responds quickly to small changes in the rhizosphere environment and the physical and chemical properties of the substrate. Although this type of root structure is conducive to water and fertilizer absorption, it also means that it is more vulnerable to high-frequency environmental disturbances. Strawberries show a significant ability to switch between stages during their life cycle, and have a flexible physiological mechanism for regulation between vegetative growth and reproductive development. Although this switch gives the plant a strong adaptability potential, its sensitivity to fluctuations in external factors also increases. Among all growth regulatory factors, the combination of light and temperature plays a leading role: high temperature accompanied by long day conditions promotes plant vegetative growth and enhances biomass accumulation; while low temperature and short day conditions effectively trigger flower bud differentiation and promote the development of reproductive organs (Koskela and Hytönen, 2018; Rivero et al., 2022).